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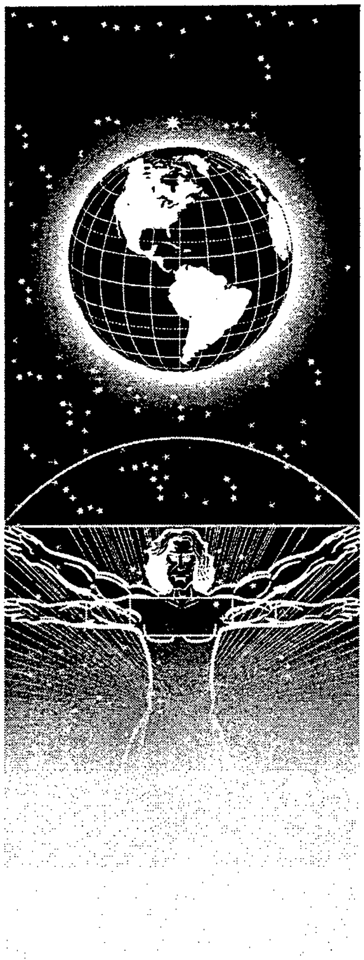

UNITED STATES AIR FORCE RESEARCH LABORATORY

Criteria and Thresholds for Adverse Effects of Underwater Noise on Marine Animals

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NOTICES

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John M. Reising

JOHN M. REISING
Crew System Interface Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

This is one of five companion reports, each of which deals with one aspect of the problem of assessing the effect of noise from military aircraft on marine life: sonic booms, subsonic aircraft noise, sound properties in air compared to sound properties in water, criteria and thresholds for risk. The purpose of this effort is to establish technically sound estimation procedures for determining the effects of military aircraft noise on marine life in water. Objectives include developing procedures for predicting properties of sound waves in air and under water as generated by both subsonic and supersonic aircraft; estimating the effects of sound on marine life, both in air and under water; determining populations of marine life at risk, as functions of aircraft, flight path, and time of year. This volume focuses on criteria and quantitative thresholds of sound for use in estimating the risk of injury or harassment to marine life. Precedent and current technical views are used to estimate that range of thresholds. The material is suitable for use in formal NEPA documentation and as background for legal arguments. While the emphasis of this report is on aircraft-generated noise, most of the material can be applied to cases of other noise sources.

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EXECUTIVE SUMMARY

This is one of five companion reports prepared under the sponsorship of the Air Force Research Laboratory (AFRL/HECB), Wright-Patterson Air Force Base (originally sponsored by the Noise Effects Branch of the Armstrong Laboratory). Each of the reports deals with one aspect of the problem of assessing the effects of noise from military aircraft on marine life: sonic booms, subsonic aircraft noise, sound properties in air compared to sound properties in water, criteria and thresholds for risk.

The end purpose of this multi-year contract effort is to establish technically sound estimation procedures for determining the effects of military aircraft noise on marine life in water. Without such procedures, the Air Force risks inadvertent violations of the law and becomes vulnerable to litigation and interference with military operations.

Objectives of the contract effort include developing procedures for:

- Predicting properties of sound waves in air and under water as generated by both subsonic and supersonic aircraft flights
- Estimating the effects of sound on marine life, both in water
- Determining populations of marine life at risk, as functions of aircraft, flight path, and time of year.

This volume specifically focuses on criteria and quantitative thresholds of sound for use in estimating the risk of injury or harassment to marine life. These factors are critically important to the compliance process: a 20 dB change (in energy or pressure level) can mean the difference between a totally safe area and a hazardous one. Likewise, the inconvenience and cost of mitigation procedures, not to mention public hearings and NEPA documentation, will depend on the risks associated with the criteria and thresholds utilized.

Although the federal laws for protecting marine life from adverse effects have been in place for over 25 years and although these laws are quite specific (see Appendix A for abstracts for NEPA, MMPA, ESA, CZMA, EO 12114, and others), there is little consensus among the regulators or the scientific community on the "amount" of underwater sound which will cause injury or harassment. In fact, the criteria and thresholds used to estimate risk are quite complicated and in a constant state of evolution.

New technical data on the effects of noise and pollutants on marine life, pressure from environmental conservation groups, and general citizen concern have led to ever increasing levels of enforcement of the various laws protecting the marine environment. Recent court cases have significantly disrupted Navy and DARPA sea tests, at substantial expense. Perhaps most distressing is that much of the litigation relates to acoustic effects on marine animals, which effects are not well understood and involve complicated physical processes outside the scope of the legal process.

What has become clear in the Navy and DARPA cases is that the most effective way to avoid

litigation and other problems is to develop high-quality, technically rigorous estimates of adverse effects well in advance of the action. Indemnification to some degree can then be acquired through mitigation schemes, documented evidence that the risk is small, or (if necessary) consultations/ permits from the regulators.

There is no question that airborne noise generated by military aircraft can cause impacts on (and even injury to) humans, animals, and structures. Because of the multiple federal and state laws protecting animals, it is not only a crime but also a serious source of civil liability to harass any marine mammal, harm members of endangered species, or "take" any of a wide variety of marine animals without a permit.

Ideally, the Air Force would have precise thresholds and standard procedures for estimating risk, so that compliance could be accomplished with minimal constraints on operations. Unfortunately, in the case of underwater sound, neither thresholds nor standard procedures have been established by agencies responsible for compliance (most notably NOAA/NMFS and USFWS) or agencies heavily involved in activities at sea (e.g., Navy, Coast Guard, MMS, NSF, DARPA).

The goal of this program is to arm Air Force with data and estimation tools sufficient to prove compliance and to actually minimize adverse effects. A key element of the effort is to provide to the Air Force the means to calculate risk based on criteria and thresholds within the "acceptable" range. In this volume, precedent and current technical views are used to estimate that range of thresholds. The material is suitable for use in formal NEPA documentation (e.g., EIS, EA) and as background for legal arguments. It is envisioned that this report will serve as a reference document, with regular updates as criteria and thresholds evolve.

As for the actual risks from aircraft-generated noise, the principal concerns are: (a) physical injury to protected marine life caused by large overpressures [shock wave and (small-amplitude) acoustic wave] and (b) harassment by the sound field of protected marine animals.

Relationships of the dose-response type have been delineated for this study, based on experimental data and theory. For example, for impulsive noises in water, a safe exposure for all marine animals but the smallest fish is one for which the peak pressure is less than 5 psi (211 dB re 1 μPa) and the positive impulse is below 5 psi·ms (211 dB re 1 μPa·ms). Precedents for 'safe' levels for harassment of marine mammals in the water are on the order of 120 to 210 dB (re 1 μPa) intensity level for non-impulsive noise and 140 to 200 dB (re 1 $\mu Pa^2 \cdot s$) energy flux density level for impulses. The harassment thresholds remain controversial, especially the impact of long duration or multiple exposures (as might occur in the case of subsonic aircraft sources and helicopters).

This report endeavors to link threshold estimates to technical references and to precedents set in formal documents (EAs, EISs). Note also that while the emphasis of this report is on aircraft-generated noise, most of the material can be applied to cases of other noise sources, such as explosive ordnance or missile entry into the water.

Finally, note that the Air Force Research Laboratory (HECB), sponsor of this effort, has in the past pursued the marine animal issue along several avenues to ensure compliance with environmental regulations and to pre-empt challenges to Air Force flight operations.

Range of Criteria and Thresholds

Criteria and thresholds for compliance with MMPA and ESA are controversial topics, and have been since 1994. There are at least two reasons for this: there are very few measurements of the impact of sound on protected species and the laws themselves are difficult to interpret. Especially problematic is 'harassment' under the MMPA, which involves criteria based on behavioral reactions. The result is a wide range of acoustic thresholds for harassment, with precedents documented in each formal risk assessment approved by regulators. It is important for Air Force to have current background on precedent, and to be able to defend its own risk assessments. This report was developed to help provide that information.

Motivation for this report is made clearer when examples of recent risk assessments (mostly from Navy and DARPA, where the majority of underwater sound assessments are conducted) are compared, as in the table below.

EXAMPLES OF CRITERIA AND THRESHOLDS FOR IMPACT ON MARINE MAMMALS

TYPE OF NOISE	CRITERION	THRESHOLD
Single Impulse	Lung Injury - 1% Mortality for Calf Dolphin	Positive impulse near surface of 25 psi-ms for explosive-like waveform
Single Impulse	Ear Drum Rupture (Injury)	Energy Level of 205 dB
Single Impulse	Permanent Threshold Shift in Hearing	RMS Pressure Level of 190 dB
Single Impulse	Temporary Threshold Shift	RMS Pressure Level of 180 dB
Single Impulse	Temporary Threshold Shift	Energy Level of 200 dB for Explosive-Like Spectrum
Low Frequency, one minute duration, non-impulsive	Physical Injury	SPL of 180 dB
Low Frequency, one minute duration, non-impulsive	Behavioral Harassment for 2.5% of whales and dolphins exposed.	SPL of 150 dB
One-second mid-frequency sonar ping	Temporary Threshold Shift	SPL of 190 dB
100 sonar pings over several hours	Temporary Threshold Shift	SPL of 170 dB
6 hours of continuous, low-frequency noise	Behavioral Harassment of 50% of whales and dolphins exposed	SPL of 120 dB
Mid-frequency sonar ping	Behavioral Harassment	SPL of 160 dB for mysticetes
Mid-frequency sonar ping	Behavioral Harassment	SPL of 180 – 190 dB for small odontocetes

For impact of noise in water on marine life from Air Force overflights, the corresponding thresholds of interest are those for impulsive signals as applied to sonic booms and those for non-impulsive signals as applied to (subsonic) aircraft flights, including helicopters. Non-auditory injury is not an issue for even the most conservative thresholds for impulses (5 psi peak pressure or 5 psi-ms positive impulse). Harassment in the form of TTS is unlikely for all cases except those of long or repeated exposures.

Behavioral harassment for the lowest thresholds considered is possible for a few cases. These are considered in companion reports. For 'middle-of-the-road' thresholds and criteria in use today, it can be argued that impact on marine life in water from Air Force aircraft is insignificant.

CONTENTS

1.0 INTRODUCTION

1.1 FIRST OF SERIES OF FIVE REPORTS

This is one of five companion reports prepared under the sponsorship of the Air Force Research Laboratory (AFRL/HECB), Wright-Patterson Air Force Base (originally sponsored by the Noise Effects Branch, Armstrong Laboratory). Each of the reports deals with one aspect of the problem of assessing the effects of aircraft-generated noise on marine life:

> **REPORT I: CRITERIA AND THRESHOLDS FOR ADVERSE EFFECTS OF UNDERWATER NOISE ON MARINE ANIMALS**
>
> Report II: Subsonic Aircraft Noise at and beneath the Ocean Surface: Estimation Models for Metrics Associated with Effects on Marine Mammals
>
> Report III: Supersonic Aircraft Noise at and Beneath the Ocean Surface: Estimation Models for Metrics Associated With Effects on Marine Mammals
>
> Report IV: Background Definitions and Metrics for Sound Properties in Air and in Water Relevant to Noise Effects
>
> Report V: Marine Animal Populations for Ocean Regions of Interest to Air Force Flight Operations

This volume deals with criteria and thresholds for estimating risks to protected marine animals, while the other reports address estimation of aircraft-generated noise and animal populations, as well as the metrics and units of sound properties in air and in water.

1.2 CRITERIA AND THRESHOLDS

The specific focus here is on the criteria for injury and harassment under the Marine Mammal Protection Act (MMPA) and the endangered species act (ESA) and the quantitative measures of sound which are used to estimate the risk of injury or harassment to marine life. By 'criterion' here we mean a specific physical injury or behavioral reaction that is judged to violate the law (e.g., ruptured eardrum or panic reaction). By 'threshold' we mean the acoustic level (in some metric) for which that particular injury or behavioral reaction is expected to occur (e.g., impulsive energy of 1.1 psi-s for eardrum rupture in 50% of the mammals exposed, or 1 W/m^2 of acoustic intensity to cause avoidance of a habitat).

These measures were determined from thresholds appearing in recent environmental assessment documents and dose-response types of relationships evolving from current research.

The thresholds for negative effects of underwater sound on marine animals are in a state of evolution, principally because of chronic legal actions against Navy and Coast Guard entities for alleged injuries to marine mammals. Hence, it is prudent for Air Force to anticipate challenges by

preparing evidence on the chances of risk, and by establishing mitigation procedures to render the risks insignificant.

1.3 ORGANIZATION OF REPORT AND APPENDICES

This report is organized with the environmental planner in mind. In the main body, each section addresses one type of sound, one type of marine animal, and the medium (e.g., impulsive noise impact on sea turtles under water). For each case, a summary of the range of criteria and thresholds used in compliance documents over the past several years is presented. This is followed by a short recount of the opinion of the authors of this report as to what is a practical, defensible range that the Air Force might use for aircraft noise compliance actions. Whereas the historical summary is objective, and based largely on public documents (mostly Navy, DARPA, NOAA, NRC, and Air Force), the opinion about what Air Force might actually apply for a given problem is strictly subjective, perhaps to be viewed as a starting point. At the same time, the user must be aware of the more conservative (i.e., more stringent on the Air Force) possibilities, and be prepared to argue against them.

Background on criteria and thresholds is usually needed to explain and justify a choice. To make the report easier to use, the bulk of the background information is found in appendices at the end of the report. The appendices are intended to provide the origin of and rationale behind the criteria and thresholds of the main text. They are envisioned as collections of materials which will grow over time, and may repeat some of the information in the main text.

1.4 ACKNOWLEDGMENTS

Much of the background information (e.g., the NMFS Criteria Workshop, certain EAs and EISs) was gathered over the years in the course of studies for Navy [ONR, CNO(N45G), CNO(N87), NAVSEA PMS 350A, NAVSEA PMS 292, NSWC-Carderock, NAVSEA PMS 92, NAVAIR] and for SAIC.

The authors are pleased to acknowledge the guidance and interest of the sponsor, especially Major Jeffery Fordon, Dr. Robert Lee, Captain Michael Carter, and Dr. Micah Downing.

2.0 BACKGROUND ON CRITERIA AND THRESHOLDS FOR ADVERSE EFFECTS ON THE MARINE ENVIRONMENT

For aircraft-generated noise, the principal concerns are (a) physical harm to marine life caused by large overpressures (shock wave and acoustic wave) and (b) harassment of marine animals caused by the sound field. In each case, the criteria for injury and harassment under MMPA and ESA are by no means well defined in the language of the laws, nor has specific guidance been issued by the regulators (NOAA/NMFS and DOI/USFWLS). In fact, the interpretation of the meaning of 'harassment' under the laws is the subject of intense on-going debate (e.g., see the recent NRC (2000) report, dedicated to this topic).

Even when the criterion is well-defined, there is usually not enough definitive evidence to determine precise thresholds of noise at which the adverse effects are suffered by each species of marine life. The thresholds and metrics currently in use for compliance documents are based on theory, extrapolation, and very limited amounts of measured data. For some cases, the range of opinion is quite large, leaving a significant amount of uncertainty in the calculated effect. Because the threshold levels continue to evolve as more is learned, this report anticipates changes by considering the range of values with significant possibility for adoption by regulators.

Of the various criteria thresholds in air and in water for injury to marine life and harassment of marine mammals, the most controversial are the levels in water for harassment of mammals and sea turtles. This report emphasizes those issues.

2.1 LAWS GOVERNING PROTECTION OF MARINE ANIMALS

The National Environmental Policy Act (NEPA) of 1969 prescribes procedures for complying with environmental laws, including the Environmental Impact Statement (EIS) and the Environmental Assessment (EA). Executive Order 12114 extends NEPA to most regions outside the United States.

Since the Marine Mammal Protection Act (MMPA) first became effective in 1972 (cf Appendix A), there have been ever increasing levels of government enforcement, litigation and public interest. Recent cases involving Coast Guard, Navy, and ARPA have led to severe program impact and penalties for harassment of marine mammals. Note that the law applies to virtually all waters, worldwide.

MMPA regulations make it illegal to "harass, hunt, capture or kill ... any marine mammal." Thus MMPA, as amended, defines "taking" to include harassment of marine mammals. Harassment is defined in recent amendments to MMPA as (paraphrase) *any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or disturb a marine mammal by causing disruption of behavioral patterns including migration, breathing, nursing, breeding, feeding or sheltering.* (see Appendix A, NRC (1994), Richardson, 1995). The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce is named in the MMPA as regulator for the Act for all cetaceans (whales and dolphins) and most pinnipeds (seals and sea lions). The United States Fish and Wildlife

Service (USFWS) in the Department of the Interior is responsible for those marine mammals not under NMFS (polar bears, sea otters, walrus, and sirenians).

A number of harassment cases, as well as the various types of NEPA documentation submitted prior to have necessarily focused on potential physical and auditory harassment of marine animals caused by sound energy. "Harassment" in that event includes the list given above, with additional interpretations: hearing damage, hearing threshold shifts, masking, cause for avoidance, and interference in communication.

Recent experience with DOD systems has shown that even the appearance of violation of the MMPA or related laws (esp. Endangered Species Act (ESA) and National Environmental Policy Act (NEPA)), much less an actual violation, can lead to expensive litigation and disruption of military missions. Hence, it is prudent for the Air Force to determine in advance the potential adverse impact on marine animals caused by military aircraft activities.

Volumes, literally, have been written in the past five years about "acoustic harassment" of marine mammals, primarily because of the enforcement and litigation issues mentioned above. Richardson et al (1995) and NRC (1994) are noteworthy. At issue throughout is the lack of consensus on acoustic metrics and thresholds that are indicative of harassment for specific species. For example, a 120 dB (re 1 μPa) sound pressure level for a pure tone in water has been adopted by some as the harassment threshold (see NRC (1994)). On the other hand, broadband impulsive noise is treated by others as harassing if the energy level exceeds 170 dB (re 1 μPa^2-s) in the auditory band of the mammal. Recent studies on human divers has led to a 130 dB sound pressure level at which low-frequency (< 1000 Hz) tones are believed to cause harm.

Sonic boom levels in air of 1 to 2 lbs/ft^2 (psf) are known to bother humans, and can be expected to bother marine mammals with ears out of the water. However, harassment levels are generally not known -- especially for mammals with good low-frequency sensitivities (the baleen whales and some sea lions).

It should be mentioned here as well that a wide variety of marine animals other than mammals are protected from harassment by ESA. Nearly any coastal or shallow-water region will have its share of endangered species ... especially listed sea turtles, fish, and sea birds. In addition, pursuant to the Magnuson-Stevens Fishery Conservation and Management Act, federal agencies are required to address essential fish habitat (EFH) requirements to determine if proposed activities have the potential to adversely affect EFH.

2.2 TYPES OF NOISE

For aircraft generated noise, regulations and the literature usually distinguish between sonic booms and noise generated by subsonic flight. For underwater noise, there is a similar distinction between impulsive and non-impulsive types of noise.

The documentation and regulators tend to treat impulsive noise and non-impulsive noise differently. Precise definitions for impulsive and non-impulsive are not agreed upon, at least not

within the underwater noise community (see the discussion of the NOAA/NMFS Criteria Workshop of 1998 for evidence of this).

As a practical matter, however, noise generated by explosives, airguns, sonic booms, and sparkers is usually treated as impulsive. Noise generated by underwater projectors (including sonars), surface ships, machinery, wind/wave action, subsonic aircraft and projectiles is usually considered as non-impulsive, even for very short pulses and broad bandwidths.

Although a definition based on it cannot be made consistent, the common element among the impulsive noises listed is that near the source there are finite amplitude effects, possibly including shock waves. Sharp rise time, high peak pressure, and a broad spectrum are usually present (at least near the source).

This distinction is reflected in the metrics used for injury and harassment thresholds under MMPA and ESA. For impulsive noise, the properties used to estimate impact include: peak pressure, energy flux density, sound exposure level, pulse duration, positive impulse, energy density in a band, and rms pressure. For non-impulsive noise, metrics are usually intensity, rms pressure, pulse length, and intensity in a band. Energy measures are seldom used for non-impulsive noise.

Even though there are metrics in common (energy, rms pressure) for these two types of noise, injury and harassment thresholds are not the same. This is the case both for water and airborne noise, for animals and humans. However, there is almost always some confusion associated with these metrics (e.g., using an intensity threshold for an impulse). This report attempts to minimize the confusion by defining the metrics in each case.

Finally, the criteria and thresholds used to estimate impact of underwater noise caused by sonic booms are generally the same as those for underwater explosives and airguns (i.e., in the impulsive noise class). Hence this report includes discussions on impact of general impulsive noise. Similarly, the thresholds for non-impulsive sound are those applied to subsonic aircraft noise, just as for sonars.

2.3 KEY EVENTS AND SOURCES OF INFORMATION

There are several events and sources of information that are important contributors to the current views on underwater noise impact expressed by regulators, the scientific community, and environmental planners. They will be cited throughout this report in discussions of criteria and thresholds. (when decibel quantities are used, they are referenced to 1 μPa).

EVENT/DOCUMENT	NOTABLE CONTRIBUTION
Lovelace Foundation Research (1960's and 1970's), Reports of Yelverton, Richmond, et al.	These test results on submerged terrestrial animals and small explosives remain the cornerstone for all thresholds for injury for marine mammals. The results have been used for virtually all Navy compliance documents for explosives since 1980. Models based on these data make up the mammal injury part of the SEAWOLF 'standard.'
J. F. Goertner (1978, 1982)	Models for explosive injuries to mammals and fish
Richardson et al. (1986) and Malme et al. (1983, 1984,1990)	Observations of effects of continuous noise and seismic sources on marine mammals.
O'Keeffe and Young (1984)	Handbook for impact of explosives on marine animals.
Klima et al. (1988)	Effects of explosions on sea turtles
Young (1991, 1992)	Range estimates for effects of explosives on marine animals
DDG-53 LOA (1994) and Ship Shock Trial (1995)	Environmental advocates delayed explosive testing until risk of harassment impact was seen to be reduced by increased mitigation.
Amendment to MMPA (1994)	Added list of examples for harassment of marine mammals and brought attention to underwater sound as possible cause.
National Research Council (1994, 1996, and 2000)	Reports of panel of experts on the effects of low-frequency noise (especially ATOC and the ATOC MMRP) on marine life.
DARPA's ATOC Tests (1995)	Legal actions brought attention to possible impact of low-frequency sound on marine mammals. ATOC used low-power sources (195 dB re 1 μPa at 1 m), but was accused of harming mammals.
Richardson et al. (1995): *Marine Mammals and Noise*	The book of Richardson et al (1995) is quoted in most discussions of sound impact on mammals. It contains good summaries of observations to 1995, especially for airguns, vessel noise and machinery noise.
Ketten (1995)	Chapter of textbook with estimates of injury from explosives to marine mammals
Strandings of 13 beaked whales on Greek coast/islands in 1996	NATO low and mid-frequency sonars were accused in print of causing whales to strand. Sonars were funded by ONR.
First TTS Studies of Ridgway et al. (1996-1997)	Navy sponsored tests of captive dolphins led to recommended thresholds for TTS and behavioral impact for tactical sonar pulses. Results widely used and extrapolated to other species and source types.
SEAWOLF Shock Trial FEIS (1998) and NOAA Final Rule (1998)	NOAA/NMFS issued Final Rule agreeing with MMPA and ESA compliance approach to ship shock trials. Injury and harassment criteria and thresholds used as 'standards' for discrete explosives. TTS approved for this case as harassment criterion under MMPA.
LFA-SRP and MMRP (1996-2000)	Research programs conducted as part of agreements for EISs for ATOC and SURTASS-LFA. Results showing only small impact of low-frequency continuous sound on baleen whales for received levels up to 155 dB. Some scientists see behavioral impact in vicinity of 130 dB levels. Results were used to construct conservative harassment thresholds for both the SURTASS-LFA DEIS and the continuation of ATOC. Long-term-exposure thresholds approach 120 dB.

EVENT/DOCUMENT	NOTABLE CONTRIBUTION
HESS Committee (1997 ff)	Reported a harassment level for marine mammals for impulsive sound of 180 dB (rms pressure). Recommended for airgun noise, but also applied to explosives.
NMFS Acoustic Criteria Workshop (1998)	Panel of experts discussed criteria and thresholds for injury and harassment of marine mammals. No report was written, but panelists seemed to agree on: (1) results of the HESS committee, (2) TTS results of Ridgway and Schusterman, (3) exposure-time rule for TTS threshold of 5 dB reduction per doubling of time, (4) proposal that PTS could occur at levels 10 dB above those causing TTS.
Kastak, Shusterman, et al TTS tests on pinnipeds (1999)	Recent, important result is that of TTS on seals and sea lions from 20-minute exposure to octave band noise near 1 kHz with levels of 135-145 dB. These very low thresholds (compared to levels used in the past) make many sound sources problematic. In addition, when combined with the Ridgway dolphin data, as done at the NMFS Workshop, it yields a strong time dependence rule for exposure to continuous sound.
"Ridgway-Schusterman-Gisiner-NIOSH" Curve, Plus Ketten (1998)	TTS and PTS threshold levels for long/multiple exposures of marine mammals – discussed at NMFS Criteria Workshop (1998)
Point Mugu Range EIS (1999)	Estimation of impact of sonic booms and aircraft noise on marine animals in Navy range.
NUWC TM (1999)	Documentation of approach to risk calculation of the Navy's East Coast Shallow Water Training Range. Harassment criteria and thresholds for mid—frequency projectors.
ONR Workshop Report (1999)	Report on workshop on effects of man-made noise on marine mammals.
Strandings of beaked whales in Bahamas (2000)	Much attention from press. Navy sonar exercises blamed (ONR's LWAD 00-1 and Navy ASW exercises). Mid-frequency tactical systems suspected. LWAD 00-2, planned for NE Atlantic, was then cancelled as a result of a NMFS Section 7 ESA consultation.

Criteria and thresholds used today in formal compliance documents for underwater noise impacts on protected marine animals will likely refer to several of the above references in establishing criteria and thresholds.

2.4 STANDARDS

For a single impulsive signal, the criteria and thresholds of the SEAWOLF Shock Trial FEIS (1998) has become the 'standard' for Navy and has been found acceptable by the regulator (NOAA/NMFS Final Rule, 1998). The approach uses several of the references listed above: the Lovelace data, the Ridgway TTS results, and Ketten (1995). Note that the HESS committee recommendations are not inconsistent with the above.

For multiple impulsive exposures (e.g., for multiple aircraft sonic booms), corresponding standards have not been agreed upon. One approach proposed by ONR and others during the NMFS

Workshop uses a 17 log N rule for lowering the threshold for TTS - i.e., the harassment threshold for a single exposure is reduced by 17 log N for N exposures. At 5 dB per doubling of the number of exposures, this rule has significant implications, even for a few sonic booms. Others have proposed 10 log N and 5 log N rules, based on equal energy and other arguments.

There is definitely no 'standard' adopted by Navy or NOAA/NMFS for injury or harassment by non-impulsive sound in water (including airplane noise). In fact, the range of thresholds for recent compliance documentation reviewed by NOAA/NMFS (under ESA consultation and under MMPA for permits) includes levels from 120 dB to 200 dB for harassment by a single pulse.

One conclusion is that the gap between what the law requires (no harassment or injury without a permit) and what is known about the character and strength of acoustic noises that might cause injury or harassment. If the most conservative thresholds were to be accepted by the Air Force, then many aircraft-generated noises could be labeled as potential causes of harassment - both in air and in water. To avoid having to accept the most conservative thresholds, this effort seeks to provide technical evidence to argue for less stringent thresholds. Key reference documents are essential elements for the derivation and justification of criteria and thresholds.

3.0. CRITERIA FOR IMPACT OF UNDERWATER NOISE ON MARINE MAMMALS, SEA TURTLES, AND OTHER MARINE ANIMALS

Throughout this report, 'criteria' for injury or harassment are stated in terms of the impact on the animal by the noise field, as opposed to properties of the noise field itself (described by the 'thresholds'). Criteria used in the past include: mortality, slight lung injury, onset of serious GI injuries, temporary hearing loss, avoidance of an area, interruption of vocalizations, masking of communications. For a given criterion (e.g., eardrum rupture in a whale), a threshold describes the sound field properties that are believed to cause the injury or harm (e. g., impulsive noise field with energy flux density in excess of 1 J/m^2).

Below are listed a number of criteria from the literature and compliance documents. Since there are several types of impacts for each law, the section is organized as follows:

LAW	IMPACT	ANIMAL	SUBSECTION
MMPA and ESA	Injury	Marine Mammals	3.1
MMPA	Harassment (Level B)	Marine Mammals	3.2
ESA	Harassment	Marine Mammals	3.3
ESA	Injury and Harassment	Sea Turtles	3.4
ESA	Injury and Harassment	Fish and Sea Birds	3.5

Because the laws are not specific in defining criteria, it is important to know what criteria have been used in the past, as well as trends in the choice of criteria. What follows is a summary; Appendix D provides additional reference material.

3.1 INJURY OF MARINE MAMMALS UNDER THE MMPA AND ESA

Whether shock waves or linear waves, there is no question that significant overpressures can cause physical injury to marine life. A single high-pressure event has been known to cause injury or death. Protected marine life subject to injury includes not only marine mammals, but also endangered species of fish, sea birds (diving and not), and sea turtles.

3.1.1 Criteria for Non-Auditory Physical Injury from Underwater Impulsive Noise

For impulsive noise, criteria for physical injury are derived largely from the Lovelace Foundation tests of the 1960s and 1970s (e.g., Yelverton et al, 1973 and 1981) and the applications of the Navy's UERD group published in the 1970s and 1980s (e.g., Goertner, 1978). Specific injuries to submerged terrestrial animals from small explosives were delineated, and became the traditional list for marine mammals injuries in water. These include lung hemorrhage, gastro-intestinal tract injury, and eardrum rupture. The common factor is the presence of gas.

Criteria for injury from impulsive noise that are used in modern compliance documents are with few exceptions based on the above research. Thus, for example, the Navy's SEAWOLF Shock

Trial FEIS (1998) lists the following criteria for injury:

CRITERIA FOR INJURY -- FROM SEAWOLF FEIS (1998)
Lethality from high peak pressure
Lethality due to cavitation
Extensive lung hemorrhage (50% mortality) for a calf dolphin of 12.2 kg.
Onset of extensive lung hemorrhage (1% mortality) for a calf dolphin of 12.2 kg.
Brief physical discomfort
Onset of slight lung hemorrhage for a calf dolphin of 12.2 kg.
50% tympanic membrane rupture
Tactile Perception

As discussed in the sections on thresholds below, the bold-faced criteria have been endorsed for the SEAWOLF case by NOAA/NMFS, and are often used by Navy as a 'standard' for risk assessments involving explosives. Specifically for SEAWOLF, the 1% mortality criterion is used to estimate risk of mortality, and the 50% tympanic membrane rupture criterion is used to estimate risk of injury.

Air Force has recently used different criteria for in-water effects of explosive tests [Eglin mine clearance tests, NOAA/NMFS(1998b)]. The criterion used for injury is based on Yelverton (vice Goertner) estimates for the level at which no marine animal (including small fish) is expected to be injured. This is significantly more stringent (more conservative) than the SEAWOLF criterion for injury. As noted below, a much more conservative version of the SEAWOLF threshold for harassment was also used for the Eglin take request.

3.1.2 Criteria for Non-Auditory Physical Injury from Underwater Non-Impulsive Noise

Except perhaps for auditory damage, non-impulsive (continuous, persistent) noise is not known to cause physical damage to marine animals, principally because the large peak pressures are almost never present. Note, however, that adverse physical effects are suspected for human divers exposed to low-frequency tones (below about 1000 Hz). These effects include possible lung resonance vibrations and inner ear disturbances. This type of injury is included among the criteria for the SURTASS-LFA DEIS (1999).

The theoretical work of Crum and Mao (1992) has been cited in NRC(2000) and various compliance documents. It may also demand attention in risk assessments for low-frequency sound of very high intensity in transmitting energy to entrained gases in the blood of submerged mammals.

While there is no conclusive evidence to date, Navy sonar systems operating in the mid and low-frequency ranges have been considered to be possible causes for the stranding of beaked whales in two incidents (Greece in 1994 and the Bahamas in 2000). One hypothesis is that these sonar signals in some way cause vestibular trauma, leading to disorientation, dizziness, or panic.

3.1.3 Auditory Injury as a Criterion for Injury – for Impulsive and Non-Impulsive Noise

Although apparently not used in DOD compliance documents to this point, scientists and regulators seem to agree that Permanent Threshold Shift (PTS) should in some cases be treated as Level A (injurious) harassment. In fact, NMFS has noted that even Temporary Threshold Shift (TTS) may have injury implications (Final Rule for SEAWOLF, 1998).

It is likely that future risk estimates will have to include PTS in the injury category. Just as for TTS as a harassment criterion (discussed below), the extent and severity of the hearing damage must be taken into consideration. No guidance has been published, but the topic received attention at the NMFS Criteria Workshop (1998). At that time it was proposed that whenever TTS can occur, PTS can also occur, through extended exposures or greater intensities. Specific thresholds for these criteria are discussed later in this report.

3.2 HARASSMENT (NON-INJURIOUS, LEVEL B) OF MARINE MAMMALS UNDER THE MMPA

The 1994 Amendment to the MMPA provides more specific language for harassment than did the original law. It thus also provides an interpretation for harassment under MMPA that is more specific and stringent than that under ESA. Hence, this subsection is dedicated to the special case of harassment under MMPA.

Besides distinguishing between injurious harassment (Level A) and non-injurious harassment (Level B), the amendment to the MMPA provides examples of harassment:

> "any act of pursuit, torment, or annoyance which:
>
> > Level A – has the potential to injure a marine mammal or marine mammal stock in the wild; or
> >
> > Level B – has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

The important distinction here is that the MMPA specifies that it is illegal (without a permit) to harass a single marine mammal, while the ESA makes it illegal to harass endangered species to the extent that the stock of that endangered species is threatened. Causing a significant behavioral reaction in a single northern right whale may thus be illegal under MMPA and ESA, but such a behavioral reaction in a sperm whale in the north Atlantic may be illegal only under MMPA.

Under ESA, the fraction of the stock impacted is usually reported in compliance documents and for Section 7 consultations. However, under MMPA, numbers of harassment 'takes' for each species are specified -- at least for cases in which only a few or no takes are expected.

Because the MMPA is the more stringent law for harassment of endangered marine mammals, it requires more detailed considerations for risk assessment.

As emphasized many times in this report, criteria for non-injurious harassment of marine mammals under MMPA are neither well-defined nor agreed upon. The best information for the Air Force to have is the set of recent precedents and the views of the technical community. Whether in consultation with regulators or in court, these are the most important materials for justification of the compliance position. A summary is provided below, with details given in Appendix D.

3.2.1 Behavioral Changes

Criteria for behavioral changes used in risk assessments over the past several years have generally been derived from observations of reactions to sound rather than from fundamental behavioral science. While displacement from habitats or interruption of feeding may be the changes intended in the development of the 1994 MMPA Amendment, the practical matter of setting thresholds for given behaviors has led to the use of observed reactions. Most observations of large whales have been limited to avoidance or breathing behaviors. For small odontocetes and for pinnipeds (in water), the observations have been broader, but generally not measured under controlled situations.

The most ambitious studies of the reactions of whales to sound have been the MMRP and the LFA-SRP, both addressing low-frequency sound and with emphases on mysticetes. Observations of behavioral reactions were a byproduct in the TTS studies of Ridgway et al and Kastak et al. Other data most cited are those of Richardson, Malme, McDonald, Ljungblad, and others, as summarized in Richardson et al. (1995).

Discussions of the ONR Workshop and NMFS Criteria Workshop clearly indicated the lack of working criteria (and corresponding thresholds) for MMPA harassment (Level B). Long-term impact on populations and 'significant' reactions to barely detectable sounds, not to mention impacts on prey species, were mentioned as possible criteria for the future. Several scientists have noted that there could well be circumstances in which barely audible sounds could cause significant reaction. Subsequently, thresholds derived from the LFA-SRP and MMRP were based on low levels of exposure and reactions that were of questionable significance in the context of the MMPA (see, e.g., NRC, 2000).

Determination of criteria and thresholds is perhaps the most serious technical issue for MMPA compliance. The range of thresholds for harassment found in current risk assessments is wider than ever (e.g., from 120 dB to 200 dB for non-impulsive noise).

The acceptance by the regulator of TTS as harassment criterion for SEAWOLF was a major step toward resolving the issue (at least for discrete noise pulses). However, the interim nature of the use of TTS as the sole indicator of Level B harassment became apparent in the following passage from the same Federal Register notice:

> "The 160-dB criterion [reference to the DDG 53 LOA] is based on a behavioral response which may be of questionable biological significance in the context of a single acoustic pulse. In the case of a continuous source (e.g., industrial noise) or repeated transient sources (e.g., seismic pulses), avoidance by a marine mammal could result in changes to migration, feeding, or reproduction patterns that could affect the energetics of both

individuals and populations. However, in the context of a single, brief pulse from a detonation, a momentary startle response causing an animal to dive or momentarily change course or speed is not likely to affect either the individual or the population. Such a minor response is well within the range of normal behaviors that an animal might exhibit at any time in response to other animals or other environmental stimuli. As a result, NMFS does not normally consider these simple, singular, reflex actions (e.g., alert, startle, dive response to a stimulus) by marine mammals to be sufficient on their own to warrant an incidental harassment authorization. On the other hand, NMFS does not concur with statements made by the Navy in response to a different rulemaking that the term ''harassment" in the MMPA should be limited to changes in behavioral patterns of a magnitude that reflect an adverse reaction on the part of the animals such as intense fear or pain or behavior that is likely to harm the animal or its offspring. By statutory definition, the *de minimus* level (for Level B harassment) should be less intrusive on the animal than suggested by the Navy." (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

[As noted in the sections on thesholds below, the 160 dB referred to by NMFS is a completely different metric from the one used in SEAWOLF for harassment. In fact, the DDG-53 threshold is greater than the SEAWOLF threshold.]

Malme et al (1984), McDonald et al, 1993; Ljungblad et al, 1982, Richardson et al, 1986; Ljungblad et al, 1988 emphasized avoidance in their observations of baleen whale reactions to airguns, ships and machinery noise. These observations remain important in the establishment of thresholds for harassment.

In conducting the TTS tests on dolphins discussed above, Ridgway et al (1997) observed significant behavioral reactions from the animals at levels much lower than those required to cause measurable masked threshold shifts. As a result, compliance documents have tended since 1997 to use the levels that cause the behavioral reactions in Ridgway's tests as thresholds for harassment from a continuous source of short duration. These thresholds are usually applied to all small odontocetes, but also sometimes to all marine mammals (e.g., SEAWOLF Shock Test FEIS, 1999).

3.2.2 Hearing Threshold Shifts for Marine Mammals and Sea Turtles

Harassment of marine mammals includes significant disruption of habitat, feeding or migration patterns, etc. Various thresholds for the amount of noise it takes to cause harassment have been hypothesized. Because marine mammals depend so much on their hearing, noises that degrade hearing sensitivity may be lethal. The effects of noise include permanent threshold shifts (PTS), temporary threshold shifts (TTS), masking of predator noises, masking of communications, interference with search for food, annoyance, etc.

Certain marine animals are known to depend on their hearing for everything from protection from prey to feeding, mating, and communicating. Essentially all cetaceans (whales and dolphins) are in this category, as are sirenians , some pinnipeds, and some sea turtles. It is widely believed that even temporary degradation in hearing ability may lead to injury or death.

Because most of the indicators of harassment interpreted for the Marine Mammal Protection Act (MMPA) are difficult to measure and quantify (masking, interference, avoidance), the Navy and NOAA/NMFS have focused on one of the indicators which can be objectively measured: temporary loss of hearing sensitivity or "temporary threshold shift" (TTS).

Historically, TTS has been an important metric for human hearing, and has been studied for terrestrial animals as well, for many years. For underwater sound and marine mammals, TTS was mentioned as an example of marine mammal harassment in NMFS (1995). The topic is discussed at length in Richardson et al (1995) and Ketten (1995). Nonetheless, there were no direct measurements of the relationship between underwater noise and TTS in marine mammals through 1996. Once the results of the tests of Ridgway et al (1997) were announced (as early as 1996), many Navy compliance documents began to use the TTS criterion. For impulsive noise, the first major Navy compliance document to use TTS as criterion for harassment was the SEAWOLF FEIS (1998). In that case, it was the sole criterion for Level B harassment, and NMFS (1998) commented on it in its Final Rule of 1998 (passage above). TTS was not used as a criterion for harassment in the first drafts of the SEAWOLF EIS (e.g., the DEIS, 1996), nor was it used as criterion in the DDG 53 LOA (1995) or the SSQ-110 EA (1995). For non-impulsive noise, TTS was used as criterion for Navy applications as early as 1998 (AUTEC ER, 1998).

The Ridgway et al. (1997) paper documents temporary shifts in the masked threshold on the order of 5 dB for bottlenose dolphins subjected to 1-second tones. In applying the Ridgway result, the subject compliance documents are thus implicitly adopting the criterion of the Ridgway tests: a small (5 dB) shift in the masked threshold, where the masking field has spectrum level on the order of 25 dB above the absolute hearing threshold. [See Schlundt et al., 2000, for the recent journal article on the TTS tests]

Neither for *SEAWOLF*, nor other assessments using TTS as criterion, are the degree or extent of TTS specified as part of the criterion. Conditions stated for the *SEAWOLF* FEIS are that the energy threshold be applied to 1/3-octave bands and to different parts of the spectrum for mysticetes and odontocetes (the former limited to the band above 10 Hz and the latter to the band above 100 Hz). This is included in the NMFS Federal Register notice.

Of additional interest is the fact that most compliance documents do not link the criterion for TTS to any specific portions of the spectrum of hearing of the animals (other than the *SEAWOLF* FEIS case above). In particular, hearing loss at a single frequency or a small band of frequencies (e.g., 10 to 100 Hz or 3000 to 3500 Hz) has the same significance as the loss of hearing across a wide band. Threshold shifts of 5 dB are considered significant.

3.3 HARASSMENT OF MARINE MAMMALS UNDER THE ESA

This report emphasizes endangered species of marine mammals and sea turtles, although there is occasionally concern for endangered species of fish and sea birds.

As noted before, for marine mammals the definition of harassment under the MMPA is more

stringent than that under ESA. Hence, the criteria for Level B harassment under MMPA will generally be applicable to ESA.

3.4 INJURY AND HARASSMENT OF SEA TURTLES UNDER ESA

Just as the Lovelace Foundation measurements are the basis for current criteria and thresholds for non-auditory physical injury to mammals, fish and sea birds from impulsive sound, turtle injury criteria and thresholds are based on a few observations (see, e.g. the SEAWOLF FEIS, 1998, for a summary). Thresholds for injury were based on various physical impacts, but not graduated as for the mammal injury criteria.

Non-impulsive noise is not known to cause non-auditory physical damage to marine animals. The shock waves and large peak pressures of explosives are not found in continuous noise. There have been no controlled measurements to determine PTS or other physical injuries to marine life from such signals.

ATOC (1995), and SURTASS-LFA (1999) have addressed the possibility of non-auditory injury to marine life from low-frequency sound. Otherwise, there is no recognition of significant non-auditory impact from non-impulsive noise.

Criteria for harassment under ESA are even less well defined than those for mammals. In fact, for lack of a better approach, the criteria (and thresholds) used in compliance documents for harassment of sea turtles under ESA are generally the same as those used for marine mammals. In fact, TTS has been used as a criterion for harassment of sea turtles in the *SEAWOLF* FEIS (1998), which applies to explosive sources. The energy threshold in the FEIS is the same as that used for odontocetes in the FEIS. PTS is not addressed.

3.5 NOTE ON FISH AND SEA BIRDS

The Lovelace Foundation and NSWC reasearch have led to criteria for mortality and serious injury of fish and sea birds by explosives. Thresholds are summarized later in this report.

Non-impulsive noise is not known to cause non-auditory physical damage to marine animals, as discussed above. However, both injury and harassment of protected sea birds and fish by non-impulsive sound in water has been estimated in several compliance documents (including ATOC, 1995).

3.6 RECENTLY USED CRITERIA FOR INJURY AND HARASSMENT

The tables below summarize the most often used criteria in recent DOD compliance documents. Bold-faced items are the ones used in actual risk estimates for compliance documents.

INJURY CRITERIA – MARINE MAMMALS
Lethality from High Peak Pressure
Lethality Due to Cavitation
Extensive Lung Hemorrhage for a calf dolphin of 12.2 kg (50% Mortality)
Onset of Extensive Lung Hemorrhage for a calf dolphin of 12.2 kg (1% Mortality)
Onset of Slight Lung Hemorrhage for a calf dolphin of 12.2 kg
Eardrum Rupture: "High Incidence"
Eardrum Rupture: 50% of Subjects
Eardrum Rupture: Low Incidence
Eardrum Rupture: 10% of Subjects
Permanent Threshold Shift (PTS)
Temporary Threshold Shift (TTS)
No Physical Injury

HARASSMENT (LEVEL B) CRITERIA – MARINE MAMMALS
Temporary Threshold Shift (TTS)
Possible Significant Behavioral Reaction Behavioral Reaction – Changes in Migration Routes, Displacement Behavioral Reaction – Changes in Vocalizations Behavioral Reaction – Changes in Diving or Breathing Patterns Behavioral Reaction – Attraction to Source Behavioral Reaction – Avoidance of Area Near Sources Behavioral Reaction – Panic Behavioral Changes – Aggressiveness, Hostility
Masking
Brief physical discomfort
Tactile Perception

INJURY AND HARASSMENT CRITERIA FOR SEA TURTLES
Physical Injury, Not Specific (but thresholds derived from observed injuries from explosions)
Harassment – Same criteria as for marine mammals under ESA

4.0 THRESHOLDS FOR IMPACT OF UNDERWATER, IMPULSIVE NOISE ON MARINE MAMMALS

Criteria for injury and harassment of marine mammals by impulsive sources were discussed in Section 3. For those criteria that are most often used, numerical thresholds are summarized below. More detail can be found in Appendices E and G. The table below lists the thresholds for single exposures to impulsive noise (mostly based on explosive noise) for a set of criteria.

Table 4.0-1. Criteria and Thresholds for Injury and Harassment of Marine Mammals for Impulsive Sources as Used in Recent Compliance Documents

TEST	CRITERION	THRESHOLD
SEAWOLF FEIS (1998)	Lethality from high peak pressure	Peak pressure 1400 psi (9660 kPa)
SEAWOLF FEIS (1998)	Lethality due to cavitation	Maximum horizontal extent of bulk cavitation region
SEAWOLF FEIS (1998)	Extensive lung hemorrhage (50% mortality) for a calf dolphin of 12.2 kg.	Modified positive impulse: 99.5 psi-msec (687 Pa-sec)
***SEAWOLF* FEIS (1998)**	**Onset of extensive lung hemorrhage (1% mortality) for a calf dolphin of 12.2 kg.**	**Modified positive impulse: 55.1 psi-msec (380 Pa-sec)**
SEAWOLF FEIS (1998)	Brief physical discomfort	Partial impulse: 3.3 psi-msec (22.8 Pa-sec) within 0.035 msec
SEAWOLF FEIS (1998)	Onset of slight lung hemorrhage for a calf dolphin of 12.2 kg.	Modified positive impulse : 28.1 psi-msec (194 Pa-sec)
***SEAWOLF* FEIS (1998)**	**50% eardrum (tympanic membrane) rupture, for an animal at bottom (152 m)**	**EFD: 1.17 in-lb/in^2 (20.44 mJ/cm^2) (205 dB* EFD Level)**
SEAWOLF FEIS (1998)	Tactile Perception	Pressure > 15 psi (104 kPa) and EFD > 0.01 in-lb/in^2 (0.18 mJ/cm^2)
***SEAWOLF* FEIS (1998)**	**TTS (Level B harassment)**	**182 dB* EFD Level: Greatest 1/3 octave band level for frequencies above 10 Hz for mysticetes and above 100 Hz for odontocetes (dual threshold)**
***SEAWOLF* FEIS (1998)**	**TTS (Level B harassment)**	**12 psi peak pressure (dual threshold)**
Florida Straits LOA(1994)	Safety radius is twice range for which there is onset of slight lung hemorrhage for 100 kg mammal	Threshold for onset of slight lung hemorrhage for a 100 kg mammal is 25 psi-ms
Eglin AFB (1998)	'Safe" from physical injury	Positive impulse < 5 psi-ms
SSQ-110 EA (1995)	Harassment	176 dB* EFD Level (Total Energy)
DDG-53 LOA (1994)	Harassment	160-180 dB** EFD Spectrum Level #

EFD is Energy Flux Density * dB re 1 μPa^2-s ** dB re 1 μPa^2-s/Hz

Within the prescribed 'safety' zone, exposures to EFD spectrum levels in excess of 180 dB were estimated to occur in the band below 30 Hz and in excess of 160 dB in bands below 200 Hz. Under a spectrum-level criterion of 160 dB or 180 dB, animals that have hearing capability in the subject bands would be assumed to be harassed.

For a given threshold it would be useful to provide "safe ranges" for each case, as is done in Young (1991), Ketten (1995), etc. However, such estimates must inherently include estimates of the source properties and of the sound propagation. In the cases of Young (1991) and Ketten (1995), results are based on the theoretical, free-field propagation for an ideal explosive. These estimates and formulas are not likely to be valid in shallow water or at long ranges (relative to shot weight).

Whereas the criteria can be readily understood (although they are not always very well defined), the thresholds have complicated definitions and the metrics themselves may be difficult to estimate. Among the reasons for this: the traditional metrics for underwater impulsive signals necessarily involve the duration of the pulse, either in terms of energy or impulse. Intensity, rms pressure, SPL are averages in time, and thus sensitive to the estimated duration of the pulse. In addition, the criteria for lung injury depend on the depth of the animal, and the criteria for TTS on the hearing bands of the animal. A further complication is the sometimes difficult problem of defining and estimating these metrics at range – especially peak pressure and modified positive impulse in cases other than direct path. In fact, for none of the cases listed above using positive impulse has the calculation been made for other than an idealized field.

The thresholds and criteria for SEAWOLF in boldface are those actually used in the FEIS (1998) for 'take' estimates. They are favored at this time in Navy, and were approved for SEAWOLF by NMFS (1998). This is important primarily for the use of TTS as criterion for Level B harassment under MMPA, and the application of a threshold derived from TTS measurements on small odontocetes for mid and high-frequency tones.

4.1 THRESHOLDS FOR MORTALITY AND INJURY OF MARINE MAMMALS BY IMPULSIVE NOISE

Introduction

There is a long history associated with the risk assessment for injury to marine mammals from impulsive sounds. This is especially true for explosive-generated noise, but the same thresholds are usually applied for other impulsive noises (airguns, sonic booms, sparkers, etc.).

Most environmental assessments for activities at sea involving underwater explosives categorize risk to marine mammals in terms of (a) mortal injury, (b) non-mortal injury, and (c) Level B harassment. For one recent action, the regulator (NOAA/NMFS in this case) has distinguished between serious and non-serious injury in terms of eventual likelihood of mortality. Until 1985 or later, harassment was usually interpreted as a physical sensation felt by the animal (as opposed to harassment in the form of behavioral change). Hence, most assessments emphasized risks of the first two types, even though "safe" ranges are usually driven by Level B harassment criteria.

Explosive Sources: Thresholds for Injury of Marine Mammals by Explosives - Lovelace Foundation

Underwater explosive tests on terrestrial mammals conducted in the early 1970s are the backbone of current estimates of physical injury to the lungs, intestines and eardrums of marine mammals.

The principal experimental work is that done by Yelverton , Richmond, and others at the Lovelace Foundation (see references for Yelverton et al. and Richmond et al.). They exposed terrestrial animals to the sound field in water generated by small explosives. Models for injury to marine mammals (and other marine animals) have been developed on the basis of those data by the Lovelace scientists, as well as by Goertner (1984), Young (1991-2), BBN(1994), Ketten (1995) and others.

Thresholds for physical injury (other than auditory threshold shifts) to marine mammals (and other marine animals) by explosives remain about the same today as when they were first established. While these thresholds are subject to challenge, they almost always lead to safe ranges smaller than those for harassment and hence are useful as a lower bound or for defining a truly "hazardous" zone in which animals risk serious bodily harm. They are the basis for estimating 'takes' which are mortal or injurious. Excluded from this broad statement are auditory threshold shifts (such as TTS and PTS).

Criteria to which the thresholds correspond take such forms as: 50% mortality, onset of slight lung hemorrhage, onset of serious lung hemorrhage with 1% mortality, onset of intestinal injury, 50% eardrum rupture, etc. Thresholds are given in terms of peak pressure, positive impulse, and energy flux density (as are traditionally used for explosives) for each type and size of marine mammal. All of these threshold estimates were derived by extrapolation from experiments performed on terrestrial animals by the Lovelace Foundation.

As cited in most compliance documents dealing with explosives (e.g., ACT II EA, 1995; SEAWOLF FEIS, 1998), Yelverton (1981) fits the mammal test results to regression equations:

$$\text{Positive Impulse} = 20.5\ M^{0.386}\ \text{psi-ms - for 50\% mortality}$$

$$\text{Positive Impulse} = 13.3\ M^{0.386}\ \text{psi-ms - for 1\% mortality}$$

$$\text{Positive Impulse} = 7.2\ M^{0.386}\ \text{psi-ms - for ``no injuries''}$$

where M is animal mass in kg. Notice that the threshold increases at a rate faster than $M^{1/3}$, and the ratio of the impulse for 50% mortality to that for no injuries is about 3.

The regression formulas are quoted in most compliance documents, but not actually used to determine thresholds for injury. Instead, somewhat different curve-fits to the Lovelace data have been developed and other models used for specific types of injuries. Those models are summarized below.

Explosive Sources: Thresholds for Injury of Marine Mammals - Goertner Models

The Goertner models for injury to marine animals have served as the basis for risk estimates for most Navy compliance documents dealing with underwater explosions since the models were developed in the 1970s and 1980s. Except for the Goertner models or direct use of the Lovelace data and regression formulas given above, we know of no other quantitative models that have

been used to account for lung or GI tract injuries to marine mammals and turtles.

An overview of the Goertner model for mammals, as applied to risk assessment, is taken directly from the Florida Straits LOA (1994):

> "Using data from the Yelverton, et al. (1973) report, Goertner (1982) developed a conservative computer model for the two primary injury mechanisms to mammals exposed to underwater explosion shockwaves. These mechanisms are: (1) lung hemorrhage, and (2) contusions fo the G.I. tract. For lung hemorrhage, Goertner's model considers lung volume as a function of animal weight and depth and considers shockwave duration and impulse tolerance as a function of animal weight and depth. Injury to the G.I. tract was indexed to the ratio of peak shockwave pressure to the hydrostatic pressure at the mammal location. Injury to the G.I. tract is considered independent of mammal size and weight. ...G.I. tract injury would generally be expected to occur at ranges less than those for the onset of slight lung injury."

The baseline thresholds of the Goertner model are:

onset of slight lung hemorrhage: $I = 19.0\ (M/42)^{1/3}$ psi-msec,

onset of extensive lung hemorrhage (1% mortality): $I_{1\%} = 42.0\ (M/34)^{1/3}$ psi-ms

extensive lung hemorrhage (50% mortality): $I_{50\%} = 83.4\ (M/43)^{1/3}$ psi-ms

where M is the body mass (in kg) of the subject animal.

Goertner (1982) also developed models and threshold estimates for GI injury. The damage is estimated from

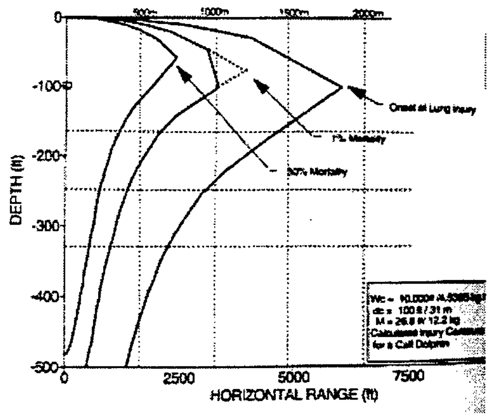
$$P_{MAX}/P_o,$$

the ratio of peak (over)pressure to hydrostatic pressure. Slight injury is estimated to occur for the case that P_{MAX} is about 600 psi and P_o is about atmospheric pressure. Animal depth is thus critical, and by 10 m the threshold for peak pressure would be 1200 psi (259 dB).

Associated with the Goertner estimates in several compliance documents has been a "peak pressure" level for lethality based on seal-bomb observations by Myrick et al. (1990). Estimated lethal peak pressures for explosives range from 1400 psi to 1700 psi (260 to 262 dB re 1 μPa), as used, for example, in the Florida Straits LOA (1994) and the *SEAWOLF* FEIS (1998).

Depth Dependence in the Application of the Goertner models.

The plot below is typical of those calculated with the Goertner lung injury model, and very similar plots can be found in Goertner(1982), O'Keefe and Young (1984), Young (1991), Richardson et al. (1995), the SEAWOLF FEIS (1998), the Florida Straits LOA (1994), etc.



Notice that the depth dependence of the range-depth curve for constant impulse can be quite significant. It is important to note in interpreting and using such results that the only depth dependence exhibited that is caused by sound propagation effects is the so-called 'cutoff' of the positive phase of the impulse by the surface-reflected path. Cutoff (or surface decoupling or ...) is important when the direct and surface-reflected propagation paths have nearly the same travel times. This is the case when the source or animal is near the surface, and is reflected in the figure by the dramatic decrease in range (decrease in positive impulse) as the source (or animal) approaches the surface. It is a direct result of the fact that the ocean surface is approximately a pressure-release boundary at which the pressure must be zero. Except for large explosives, most of the applications of the Goertner model are for short ranges in deep water, and do not include any sound propagation effects (other than cutoff by the surface-reflected path).

The decrease in range as depth increases beyond the point for maximum range (greatest impulse) is not a propagation effect. It is actually the result of the fact that the model uses (a) a strongly depth-dependent threshold and (b) significantly different definition of positive impulse to account for the diminished impact as the animal's depth increases and lungs compress (or collapse).

Specifically, the Goertner model uses a 'modified partial' impulse, calculated as

$$\int_0^{T_{MIN}} p(t)\,dt ,$$

where p(t) is the pressure wave from the explosive, at a fixed location, as a function of time. The time scale is set so that $p(t) = 0$ for $t < 0$. The upper limit of the integral is defined as:

$$T_{MIN} = \min \{T_{pos}, T_{osc}\},$$

where T_{pos} is the time to cutoff, and T_{osc} is a function of the air-bubble (lung) oscillation period. The integral with upper limit T_{pos} is the positive impulse, by definition. When $T_{osc} < T_{pos}$, then the 'partial impulse' is smaller than the positive impulse. When compared to a threshold for injury, it will thus predict less impact than would the true positive impulse.

T_{osc} is estimated in Goertner (1982) as proportional to $M^{1/3}/(1 + Z_a/33)^{5/6}$, where M is animal mass and Z_a is animal depth. It is thus a monotonically decreasing function of depth. T_{pos} is usually calculated in the isospeed approximation as proportional to

$$(R^2 + (Z_a + Z_s)^2)^{1/2} - (R^2 + (Z_a - Z_s)^2)^{1/2}$$

where R is range and Z_s is charge depth. Thus T_{pos} is 0 (and impulse is 0) when either charge or animal is at the surface. T_{pos} increases (as does impulse) with animal depth or source depth.

For a fixed animal mass, charge depth and size, the maximum range at which a specific threshold is attained corresponds in most practical cases to an animal depth for which $T_{osc} = T_{pos}$. This is the location of the range peak in the range-depth curve shown. It is easily calculated.

The thresholds (called 'risk functions' in the 1982 report) used with the modified impulse are also depth dependent. It is not clear why each one falls off so rapidly [like $(1 + z_a/33)^{-1/2}$] in all of the calculations of depth dependence. The 1982 report on mammals shows an injury function that decreases like $(1 + z_a/33)^{-1/6}$ a rate so slow that calculations of the full modified impulse against this threshold fall off much more slowly than the plots in the text. The Goertner documentation does not indicate why the faster fall-off rate applies.

Note that without the Goertner model and modification to the positive impulse, "safe" ranges for animals at depth would be many times greater.

The meaning of 'positive impulse' outside of the ideal propagation environment, and approaches for estimating it have not been addressed in any of the risk assessments reviewed.

Thresholds for Injury of Marine Mammals - Ketten (1995)

Ketten (1995) has been used as a source of information for criteria and thresholds for several compliance documents, including the recent *SEAWOLF* Shock Test FEIS (1998). Estimates are based on the Lovelace data, data for humans in water, and on data for animals and humans in air:

Table 4.1-1. Peak Pressure versus Marine Mammal Injury and TTS (Ketten, 1995)

Units		Lethal	Mixed Lethal/ PTS	PTS >50%	Mixed PTS/TTS	TTS: Moderate to None
psi		1100	350-1100	100-350	15-100	5-15
dB re 1 μPa		258	248-258	237-248	220-237	211-220

The metric is peak pressure and the estimates are intended to apply to sound generated by explosives. The TTS effects listed in the table are discussed in the in a subsequent section.

It is not possible to compare peak pressure values with the positive impulse and energy values given in previous thresholds unless information about the waveform is known. Furthermore, range

estimates based on standard 'similitude' formulas will not generally be valid in shallow water or to long range. As a result, range estimates based on these formulas are suspect if the conditions are much different from the ideal. This is the motivation for expressing thresholds in terms of sound metrics at range, rather than in terms of ranges from the source.

Thresholds for Injury of Marine Mammals - Eardrum Rupture

Eardrum (tympanic membrane) rupture has been used as an injury criterion in a number of compliance documents over the past five or more years. Thresholds have been calculated for all of these cases by CD-NSWC/UERD (Naval Surface Warfare Center, Carderock Division, Underwater Explosions Research Division).

The Florida Straits LOA (1994) describes a model based on the Lovelace data and stated as:

$$\ln R_{\%} = 3.734 + 0.719 \ln E$$

where $R_{\%}$ is the rupture percentage and E is the total shockwave energy (in psi-in). A modified version was used for the SEAWOLF FEIS (1998):

$$\ln R_{\%} = 3.778 + 0.767 \ln E.$$

The threshold, as presented, is independent of mammal mass, species, depth, and independent of charge weight and depth. The only dependencies on depth are those associated with propagation of the pulse. No depth dependence in the range contours is indicated in the Florida Straits LOA (1994).

For the SEAWOLF FEIS (1998), 50% eardrum rupture constitutes the criterion for non-fatal injury. This is the criterion used to determine injury takes and to establish a 'safe' range ('safe' from injury other than TTS). The actual threshold used is an energy flux density value of 1.17 psi-in (about 205 dB re 1 μPa^2-s).

Criteria listed in past compliance documents have included 5% through 95% rupture rates. In all cases, the thresholds have been estimated by CD-NSWC/UERD and are derived from the Lovelace data for dogs. Note that Lovelace [Yelverton et al. (1973)] provides a threshold in terms of positive impulse, while CD-NSWC/UERD use an energy model to fit the data. A sample of the estimated thresholds is given in the table below.

Table 4.1-2. Examples of Thresholds for Eardrum Rupture

Rupture Percentage	Threshold Metric	Threshold	Reference
10%	Energy Flux Density	0.14 psi-in (25 J/m^2) (196 dB re 1 μPa^2-s)	*SEAWOLF* DEIS (1996)
50%	Energy Flux Density	1.17 psi-in (205 J/m^2) (205 dB re 1 μPa^2-s)	*SEAWOLF* FEIS (1998)
"high			

incidence"	Positive Impulse	40 psi-ms (276 Pa-s)	Yelverton et al (1973)
50%	Positive Impulse	20 psi-ms (138 Pa-s)	Yelverton et al (1973)
0%	Positive Impulse	10 psi-ms (69 Pa-s)	Yelverton et al (1973)

Note that the 50% rate replaced a 10% criterion in the *SEAWOLF* FEIS evolution on the basis of confidence in the estimate of impact (rather than on the impact itself). See Appendix E for additional information.

Thresholds Used in the Eglin AFB Assessment (1998) [NOAA/NMFS(1998)]

The thresholds for injury used in the subject risk assessment differ from those used in most Navy compliance documents for explosives. A positive impulse of 5 psi-ms is used, and the metric does not include the Goertner modification discussed above. Hence, this is a much more conservative (stringent) threshold than those used in previous assessments of the 1990s.

4.2 THRESHOLDS FOR NON-INJURIOUS HARASSMENT OF MARINE MAMMALS BY IMPULSIVE NOISE

This subsection addresses thresholds for harassment of marine mammals by impulsive noise in water. Definitions of harassment and estimates of sound levels that cause harassment have evolved over the last ten years, and continue to change as more is learned about the sound fields and animal reactions. The topic is complicated and little consensus can be found in the scientific community or from regulators.

4.2.1 Introduction

As mentioned several times, the term "harassment" has no statutory definition under the ESA and only a broad definition under the MMPA. Recall that under the MMPA, Level A harassment causes injury, while Level B harassment includes (paraphrase): any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or disturb a marine mammal by causing disruption of behavioral patterns, including migration, breathing, nursing, breeding, breeding, or sheltering.

The selection of specific criteria for harassment is not guided by any formal guidance from NMFS, nor have Navy or Air Force standardized their approaches. Hence, it is important to know that Navy and NMFS have agreed in at least one case that TTS can be used as the sole criterion for harassment of marine mammals. The one case is cited often in this report: the SEAWOLF Shock Trial FEIS (1998).

See Section 3 and Appendix D for more on criteria for harassment and injury.

4.2.2 Examples of Thresholds for TTS and Harassment of Marine Mammals by

Impulsive Noise (esp. Explosives)

Whereas there has been much consistency among compliance documents of the past ten years for threshold for physical injury, there has been very little consistency in thresholds for (Level B) harassment of marine mammals and endangered species. Consider, for example:

Table 4.2-1 Examples of Thresholds for Harassment and TTS by Explosives

Document	Source of Threshold: Threshold Level	Peak Pressure (dB re 1 μPa)	EFD (dB re 1 μPa^2 s)
DDG 53 LOA (1995)	Richardson et al (1995): 160 to 180 dB SEL for Harassment. But EFD *spectrum* level of 160-180 dB actually used for risk estimates.	*(220-240)*	185-205 [b]
DDG 53 LOA (1995)	As interpreted in the SEAWOLF FEIS (1998): 160 dB Peak Pressure for Harassment.	160	(125)
SSQ-110 (1995)	Harassment for Single Shot	*(211)*	176
SEAWOLF FEIS(1998)	Ketten (1995) for TTS: 5 to 15 psi Peak Pressure. [12 psi used for FEIS]	211-221 [219]	*(176-186)* *[184]*
Richardson et al. (1995)	Richardson et al (1995) auditory DRC for PTS	214-244	*(179 –209)*
SEAWOLF FEIS(1998) [b]	Richardson et al (1995) auditory DRC for PTS, modified for *SEAWOLF* FEIS [d]	241-250	*(206 –215)*
SEAWOLF FEIS(1998)	Ridgway (1997a) and Extrapolation by Helweg and Gaspin. TTS at 182 dB[a] for odontocete band (above 100 Hz)	*(232)*	197 [a]
SEAWOLF FEIS(1998)	Ridgway (1997a) and Extrapolation by Helweg and Gaspin. TTS at 182 dB [a] for mysticete band (above 10 Hz)	*(222)*	187 [a]

( ) Italicized numbers in parentheses have been extrapolated - based on an ideal shot of moderate size under ideal conditions. In that case the peak pressure level in the band is about 30 to 40 dB greater than the EFD level, provided that the reference unit for time is the second.

[a] The threshold listed in the FEIS is 182 dB (r e 1μPa^2 s) for the largest 1/3[rd] octave band level within the hearing band (above 10 Hz for mysticetes and above 100 Hz for odontocetes). This is about 5 to 10 dB smaller than the comparable total band level, depending on shot size, depth, range, etc. The values in the table are examples.

[b] DDG 53 LOA document uses 160-180 dB energy *spectrum level* as threshold for harassment. For the low band and the approximate spectrum of the shots used, the equivalent level in the low band (up to 1000 Hz) is about 205 dB (re 1μPa^2 s)

[c] The SEAWOLF FEIS (1998) disagreed with the DRC of Richardson et al. (1995)

[d] Richardson et al. (1995) estimated thresholds for PTS based on the amount that the peak pressure level of an impulse exceeds the human hearing threshold. This is a 'dynamic range' argument in which the observed range for humans in air is about 164 dB (log measure of a dimensionless ratio). Recall that the NRC(1996) paper suggests a range of 155 dB on the basis of human hearing. If dolphins had the same hearing range, then they would reach PTS at about 164 dB above their absolute hearing thresholds (40 to 70 dB re 1 μPa for a pure tone in white noise in the best hearing bands). Peak pressures of 214 to 244 dB (re 1 μPa) are thus proposed as possible thresholds for PTS.

4.2.3 Harassment Threshold Based on TTS for Marine Mammals - *SEAWOLF* FEIS (1998)

Neither for *SEAWOLF*, nor other assessments using TTS as criterion, are the degree or extent of TTS specified as part of the criterion. Conditions stated for the *SEAWOLF* FEIS are that the energy threshold of 182 dB (re 1 μPa^2 s) be applied to 1/3-octave bands and to different parts of

the spectrum for mysticetes and odontocetes (the former limited to the band above 10 Hz and the latter to the band above 100 Hz). This is included in the NMFS Federal Register (1998) notice.

As will be mentioned in subsequent parts of this report, the Ridgway et al. (1997) paper is the basis for the threshold for SEAWOLF and at least one other compliance document (the AUTEC ER, 1998). The Ridgway paper documents temporary shifts in the masked threshold on the order of 5 dB for bottlenose dolphins subjected to 1-second tones. In applying the Ridgway result, the subject compliance documents are thus implicitly adopting the criterion of the Ridgway tests: a small (5 dB) shift in the masked threshold, where the masking field has spectrum level on the order of 25 dB above the absolute hearing threshold.

Of additional interest is the fact that most compliance documents do not link the criterion for TTS to any specific portions of the spectrum of hearing of the animals (other than the *SEAWOLF* FEIS removal of bands below 10 and 100 Hz for baleen and toothed whales, respectively). In particular, hearing loss at a single frequency or a small band of frequencies (e.g., 10 to 100 Hz or 3000 to 3500 Hz) has the same significance as the loss of hearing across a wide band. Threshold shifts of 5 dB are considered significant.

4.2.4 Ketten (1995): Marine Mammal Injury and Harassment from Explosives

Ketten (1995) has been used as a source of information for criteria and thresholds for several compliance documents, including the SEAWOLF Shock Test FEIS (1998). The table of thresholds, shown in Subsection 4.1, indicates TTS at peak pressures from impulsive noise of 5-15 psi. (211 to 220 dB re 1 μPa). A value of 12 psi (218 dB) was used in SEAWOLF.

Note that the peak pressure level of 200 to 220 dB given in the assessment of Malme et al. (1984, for air gun pulses) for avoidance is consistent with Ketten's peak levels for TTS. The extrapolated energy thresholds are not inconsistent with the SEAWOLF FEIS (1998) energy threshold for TTS (182 dB in 1/3 octave bands) or the SSQ-110 EA (1995) energy threshold for harassment (176 dB). (See Appendix E).

4.2.5 Baleen Whale Avoidance and Harassment for Air Guns (Malme, Richardson, and others)

Malme et al (1984) found that gray whales avoided areas where continuous low-frequency sounds exceeded 120 dB, but that pulsed sounds did not elicit a corresponding reaction unless the average intensity levels exceeded 160 dB (re 1 μPa).

Humpback, gray, bowhead, fin, and blue whales (all baleen whales) have been observed to continue their normal behaviors in the presence of air-gun impulses with peak pressures as high as 160 dB (re 1 μPa) (McDonald et al, 1993; Ljungblad et al, 1982). Avoidance reactions, however, were common when peak levels reached 170 dB (Richardson et al, 1986; Ljungblad et al, 1988).

Baleen whales have been observed to show some avoidance when noise pulses exceed 160-170 dB peak pressure (re 1 μPa).

4.2.6 Thresholds Used in the Eglin AFB Assessment (1998)

The Eglin AFB IHA (NOAA/NMFS, 1998) discussed in subsection 4.1 used the same criteria and thresholds for harassment as the SEAWOLF FEIS.

4.2.7 MMS/ITM (1998) Workshop: HESS Committee Findings for Thresholds

During the 1998 meeting, Pierson of MMS summarized the results of the HESS Panel.

Seven key recommendations were given Pierson. Most notable (and the one which Pierson said occupied the most time and effort) was the sound level at which problems might occur (such as harassment). The estimation of the threshold was driven by Ketten, but agreed upon by all. The threshold, for impulse sound, is an rms pressure level of 180 dB re 1 μPa. This level is to be applied to all mammals and seismic impulses. {No allowance is made for the frequency spectrum of the sound and the hearing sensitivities of the animals. In addition it is important to note that in most cases the rms pressure level lies between the energy flux density level (with second as the time reference) and the peak pressure. A typical relationship might be 170 dB (re 1 μPa^2-s) energy, 180 dB rms (re 1 μPa), and 195 dB (re 1 μPa) peak pressure.}

5.0 THRESHOLDS FOR IMPACT OF UNDERWATER, NON-IMPULSIVE NOISE ON MARINE MAMMALS

This section discusses acoustic thresholds for injury and harassment of marine mammals by non-impulsive noise (including projectors, subsonic aircraft noise, machinery noise, ship noise). This is one of the most studied and most controversial of topics in this report. In fact, risk assessments for Air Force, Navy, and others can succeed or fail based on the threshold used and its justification. Additional information and background can be found in Appendix F.

5.1 THRESHOLDS FOR INJURY TO MARINE MAMMALS FROM NON-IMPULSIVE NOISE

Non-impulsive (continuous, persistent) noise is not known to cause non-auditory physical harm to marine animals, principally because the large peak pressures of impulsive noise are almost never present. Note, however, that adverse physical effects are suspected for human divers exposed to low-frequency tones (below about 1000 Hz). These effects include possible lung resonance vibrations and inner ear disturbances. "Safe" levels for experienced and amateur divers have been established on an interim basis by the Navy at 150 dB (re 1 μPa) and 130 dB, respectively (see, e.g. ProPatria II, 1997). Whether or not marine animals suffer similar effects is not known. Recent Navy compliance documents have used thresholds for non-auditory injury in the range from 180 dB to 210 dB (re 1 μPa).

5.1.1 Conditions for Possible Injury

There are three conditions for which some injury to marine animals from non-impulsive noise has been suggested:

PTS for noise in the hearing band of the animal

LOW-FREQUENCY NOISE and possible physical injury related to vibration or resonance

MID-FREQUENCY NOISE AND BEAKED WHALES (suggested by two stranding events in which tactical active sonars have been suspected as cause).

Based on relationships reported in the literature between PTS and TTS (in humans and terrestrial mammals in air), Ketten has suggested that PTS in marine mammals may occur at stimulus levels of order 10 dB above those that cause TTS (NMFS Criteria Workshop, 1998).

ATOC (1995) and LFA-SRP (1999) have addressed the possibility of harm to marine life from low-frequency sound. Otherwise, there is no recognition of significant non-auditory impact in Navy analyses.

The strandings of at least 12 beaked whales off the coast of Greece in 1986 (Frantzis,1998 and D'Amico, 1998) and in the Bahamas in March 2000 have been attributed by some to active sonar emissions. Suspicions are of vestibular trauma, causing disorientation. There are no definitive

results for either case, but the incidents have led to considerable publicity and special attention from the regulators. That mid-frequency, non-impulsive noise could cause the trauma responsible for strandings is a new and unproved concept. Note that injuries to the beaked whales in the Bahamas were reported to be physical (including some hemorrhaging), but not considered serious. The strandings are suspected to be the result of disorientation and perhaps panic (NOAA/NMFS press release).

5.1.2 Further Notes on Non-Auditory Injury to Marine Mammals Caused by Non-Impulsive Signals

Projectors, even those as powerful as the SURTASS-LFA or AN/SQS-53 sonars, have not been known to cause non-auditory physical injury in marine mammals. Whereas the smallest explosives can cause serious injury at range, projector signals do not exhibit the peak pressures and broadband, impulsive waveforms of explosive signals. The peak pressure referred to one meter will not exceed 250 dB for the most powerful sonar array (which itself has dimensions of several wavelengths), while a 1.8 pound SUS charge has peak pressure of order 260 dB at one meter.

Less efficient sources of underwater noise, including aircraft and surface ships, are likewise not able to produce the peak pressure level associated with injuries.

In tests on dolphins and beluga whales, Ridgway et al. (1997) found that levels in excess of 200 dB for short mid and high-frequency tones caused no physical harm, except TTS (see Schlundt et al., 2000). In attempts to simulate explosive signals at range, acoustic projectors produced peak levels as high as 220 dB without any TTS or other physical impact on dolphins or beluga whales (See the recent Finneran et al., 2000. Note that the peak pressures and spectral content of explosive signals at ranges sufficient to cause onset TTS could not be simulated with projector arrays.)

Richardson et al (1995) state that, “We have seen no reports demonstrating whether high levels of steady or impulse noise cause “discomfort” or nonauditory physiological effects in marine mammals.”

NRC (1996) has a subsection dedicated to “ Potential Nonauditory Acoustic Effects on Marine Animal Health.” This follow-on to the 1994 NRC report on low-frequency sound impact mentions only the Crum and Mao (1996) and Lettvin et al (1982) studies on bubble growth in tissues caused by exposure to intense, low-frequency sound. In that case, it is hypothesized that marine mammals may be injured when exposures exceed 210 dB (re 1 μPa) SPL for at least several seconds. This is a theoretical result and there is no evidence that such an injury may actually occur in either humans or animals.

Cudahy and others presented on overview of non-auditory physiological impact to human divers from low-frequency projectors at the 1998 ONR Workshop (Proceedings, 1999). Some of this work was in support of the LFA system (SURTASS-LFA DEIS, 1999). From the ONR report 1999), two statements are relevant:

Diver Exposure Limits for LF Sound "It [NAVSUBMEDRSCHLAB, 1995] gave the maximum level as 160 dB for a 100 second signal between 160-320 Hz for a total of 15 minutes with a maximum 50% duty cycle."

Diver Non-auditory Sensing of LF Sound. "The Navy Environmental Health Center (NEHC, 1997) specified that 130 dB SPL at dives sites was the maximum level used in the current sea research program. This number was based on the minimum threshold for vibrotactile sensing of an underwater sound between 100 and 500 Hz.

The SURTASS-LFA DEIS (1999) uses an injury (non-auditory) threshold for marine mammals of 180 dB (re 1 μPa) for LFA signals (up to 100 seconds in duration and in a band from 200 to 600 Hz). This threshold is as low as any for injury for marine mammals. Compare to the Ridgway TTS tests at 500 Hz (Schlundt et al., 2000) on dolphins and beluga whales, for which neither injury nor TTS was found to occur for 1-second tones at levels as high as 190 dB.

The table below summarizes the various thresholds given above:

Table 5.1-1 Thresholds for Injury for Non-Impulsive Noise

Exposure SPL (dB re 1 μPa)	Exposure Time	Effect	Reference
210	seconds?	theory that injury to mammals could result from bubble growth in tissues caused by low frequency signal	Crum and Mao (1996)
160	100-sec. signals, over 15 min. at 50% duty cycle	"safe" exposure level for divers and LF signals	NAVSUB-MEDRSCH-LAB (1995)
130	seconds	sensing by diver of low-frequency signals	ONR Workshop (1998)
202 – 230?	one second	proposed onset of PTS for mid-frequency signal (based on 10 dB above mid-level TTS)	Ketten at NMFS (1998)
180	up to 100 second, low-frequency signal	'physical injury' to marine mammals	SURTASS-LFA DEIS (1999)
180 - 200	1 second tones at 0.5, 3, 20, 70 kHz	no injury to dolphins or beluga whales for levels up to 200 dB	Ridgway (Schlundt, 2000)
220 (peak pressure)	'explosive simulator,' a few ms	no TTS in dolphins or beluga whales	Finneran et al. (2000)
237 (peak pressure)	single explosive signal (for comparison)	"safe" level for divers	Christian and Gaspin (1974)

5.2 THRESHOLDS FOR NON-INJURIOUS HARASSMENT OF MARINE MAMMALS BY NON-IMPULSIVE NOISE

5.2.1 Overview for Single Exposures

Criteria and thresholds for non-injurious harassment by non-impulsive noise are perhaps the most difficult and controversial topics of this report. This is especially true for mid- and low-frequency noise (below about 5000 Hz), where much of the energy from subsonic aircraft noise occurs. The range of thresholds used in formal compliance documents over the past year alone is wide enough to cover the difference from benign to injurious ... from risk free to Level A harassment.

This section covers only the highlights of the topic. Appendices D (Criteria), H (Thresholds), and I (Hearing Bands) contain background materials, references, and details.

The tables below show recently used harassment thresholds for single exposures, and should illustrate the wide range of approaches in use today.

Table 5.2-1 Thresholds for *TTS* for Non-Impulsive, *Low-Frequency* Noise

Effect (Criterion)	**Marine Mammals**	**Signal Type/Duration**	**Frequency Band**	**Threshold (SPL) (dB re 1 μPa)**	**Reference**
Annoyance or TTS	all	narrowband	< 1000 Hz	80-100 dB above absolute hearing threshold	NRC(1996), from NMFS
PTS (included for comparison)	all	narrowband	< 1000 Hz	155 dB above absolute hearing threshold	NRC(1996), from NMFS
Injury (included for comparison)	all	nominal 60 second, narrowband	< 1000 Hz	100 % of animals at 180 dB	SURTASS-LFA DEIS (1999)
TTS	baleen whales	narrowband	< 1000 Hz	180 dB	LWAD EAs

Table 5.2-2 Thresholds for *TTS* for Non-Impulsive, *Mid/High Frequency* Noise

Effect (Criterion)	Marine Mammals	Signal Type/ Duration	Frequency Band	Threshold (SPL) (dB re 1 μPa)	Reference
TTS of 5 dB in masked threshold	dolphins	narrowband, 1-second tone	3-75 kHz	201-192 dB	Ridgway et al. (1997)
Absolute Hearing Threshold	dolphins	1-second tone	about 10 to 75 kHz	40 – 60 dB	see Richardson et al. (1995)
TTS	odontocetes	narrowband, < 1-second	above 3 kHz	201-192 dB	AUTEC ER (1997)
TTS	seals, sea lions	octave band, 20 minutes	below 3 kHz	135-145 dB	Kastak et al. (1999)

Table 5.2-3 Thresholds for *Behavioral* Reactions for Non-Impulsive, *Low-Frequency* Noise

Effect (Criterion)	Marine Mammals	Signal Type/Duration	Frequency Band	Threshold (SPL) (dB re 1 μPa)	Reference
"Behavioral Changes"	all	narrowband/ long term	< 1000 Hz	140 dB	NMFS post-ATOC (1995)
Avoidance	baleen whales	broadband/ long term	< 1000 Hz	120 dB	Malme et al (1984)
Harassment	all	narrowband/ long term	< 100 Hz	150 dB	ATOC (1995)
Harassment	all	narrowband/ long term	< 1000 Hz	160 dB	NMFS, post-ATOC (1995)
'Behavioral Reactions'	all	narrowband	< 1000 Hz	70 dB above absolute hearing threshold	NRC(1996), from NMFS
Behavioral Harassment	all	nominal 60 sec., narrowband	< 1000 Hz	2.5% of animals at 150 dB	SURTASS-LFA DEIS (1999)
Behavioral Harassment	all	nominal 60 sec., narrowband	< 1000 Hz	50% of animals at 165 dB	SURTASS-LFA DEIS (1999)
Behavioral Response	bowhead whales	long duration drillship	broadband, most below 5 kHz	1/3-octave-band level of 115 dB	Richardson and Wursig (1997)

Table 5.2-4 Thresholds for *Behavioral* Reactions for Non-Impulsive, *Mid/High Frequency* Noise

Effect (Criterion)	**Marine Life**	**Signal Type**	**Frequency Band**	**Threshold (SPL) (dB re 1 μPa)**	**Reference**
Behavioral Changes	dolphins	tone (1 sec)	Tones near 3, 20, 75 kHz	186-178 dB	Ridgway et al. (1997), Schlundt et al. (2000)
Behavioral Changes	odontocetes except sperm whale	< 1-second narrowband	above 3 kHz	180 dB	LWAD EAs (1998-1999), NUWC TM (1999)
Behavioral Changes	sperm and baleen whales	< 1 second, narrowband	above 3 kHz	160 dB	LWAD EAs (1998-1999)
Behavioral Changes	pilot and beaked whales	< 1 second, narrowband	above 3 kHz	160 – 173 dB	LWAD EAs (2000)

5.2.2 Multiple Exposure Rules

Ridgway and others (e.g., panel for the NMFS Criteria Workshop in 1998) have hypothesized a sound level-time relationship for TTS based on two data points (Ridgway et al., 1997 and Kastak et al., 1999). The rule proposed begins with a threshold of about 192 dB for a one-second continuous signal and reduces the threshold by 5 dB for every doubling of exposure time (or number of exposures). Thus, for example, a 16-second tone at a level of 172 dB would cause the same TTS effect as a one-second signal at 192 dB. The rule is related to a dated NIOSH relationship for long-term human exposure to broadband noise, and is sometimes represented as a "17 log T rule." Compare this to the "equal energy" rule of 10 log T, and to the various other rules found in human hearing studies. The 17 log T rule has serious ramifications for risk assessments in that 120 dB (the lowest threshold considered) is reached within about five hours of exposure. The rule and its agreement with the Ridgway and Kastak measurements has recently appeared in a published journal article (Finneran et al, 2000).

The possibility of PTS at 10 dB above TTS has been suggested by Ketten (1998) in the same NMFS Workshop (1998). Adoption of this threshold has even more serious implications for risk assessments - resulting in injurious (Level A) 'takes' at low exposure levels (e.g., 130 dB for multiple hours).

In the case of behavioral changes, multiple-exposure relationships of the type used for TTS have been only rarely applied. If avoidance is the criterion, it is not known how many exposures or for how long are needed to cause a change in behavior. For this reason, relationships of the 'A

log T' type have been used in only a few recent documents (see SURTASS-LFA DEIS, 1999, in which a 5 log N rule is used). On the other hand, a 'credit' for low duty cycles and a threshold for long term, continuous exposure have been used in the past, with a 10 log rule most common.

5.2.3 Some Examples

It is worthwhile to review the ramifications of the above thresholds and rules for typical cases, some directly applicable to aircraft noise in water. Four cases are considered:

CASE	SOURCE LEVEL	SOURCE MOTION	PING RATE/ DURATION	1- EXPOSURE THRESHOLD	MULTIPLE RULE
A	220 dB	None	Continuous	150 dB per long exposure (1 hour)	None
B	220 dB	None	1/minute	160 dB per ping	3 dB per doubling
C	200 dB	200 km/hr	Continuous	120 dB for 1 minute	None
D	240 dB	5 km/hr	4 per hour	150 dB for 2.5% of animals exposed	3 dB per doubling

Case A could apply to a hovering helicopter, although the equivalent in-water source level (near the water surface) is higher than usual. In this case, the ATOC threshold is applied, and might lead to a harassment-zone radius of about 1-2 km, depending on propagation conditions. Only a fraction of animals in the zone would be likely to remain in the zone for an hour (assuming typical swim speeds of 3 knots). An effective zone area of 6 km^2 per hour might be argued. 'Takes' would then be a concern when animal densities approached 0.1/km^2 , a relatively high, but not impossible, value for coastal US waters.

Case B is included to emphasize the effect of the multiple exposure rule. Even though the threshold for a single exposure is greater than that for Case A, notice that an exposure time of one hour might correspond to a zone radius of about 6 km, for mid-frequency sound. It would not be unusual for an animal to remain in that zone for one hour. The harassment zone is thus about 100 km^2 in area, a definite concern for odontocetes and prolonged pinging.

Case C might apply to a propeller-driven aircraft at low altitude. The very conservative NMFS threshold of 120 dB yields a zone of radius as great as 10 km. The size of the zone suggests that animals in the zone would be exposed for the full minute. Plane motion induces an ensonified area of about 200 km long by 10 km wide, or 2000 km^2 for each hour of flight at 200 km/hr. Multiple 'takes' would then be likely, since mammal densities are often greater than 0.001/km^2.

Note that for case C and a 160 dB threshold, the zone shrinks to 100 m, and the likelihood of an animal suffering the full minute of exposure decreases. Even though the ensonification area may be 20 km^2 per hour, an argument for 'no takes' is likely to succeed.

Case D is close to the SURTASS-LFA DEIS situation, although the source level is fictitious. Note here that the area ensonified at harassment level is the largest one for which animals are likely to remain in the zone for the corresponding exposure time. In 8 hours, 32 pings would be emitted, and the zone radius would correspond to a transmission loss of 240 dB – 135 dB = 105 dB. For typical low-frequency propagation conditions, the range might be about 200 km or more. The harassment area would be about 60,000 km^2 and many takes of all species would be expected for each eight hours of operation.

5.2.4 Recent Precedents and Air Force Applications

The discussion above and the many details of the appendices are now combined to suggest an approach to risk assessment for the non-impulsive case.

The criteria and thresholds which are among today's 'middle of the road' choices are listed below. These should be defensible and yet not overly conservative. We group mammals according to best hearing bands:

Class L: all mysticetes, sperm whale, california sea lion, elephant seal

Class H: all others

The thresholds are then:

Low-Frequency Noise (< 1000 Hz)

Class L Mammals:
180 dB (re 1 μPa) SPL as behavioral threshold for short exposure.
Reduce threshold by 3-6 dB for long or multiple exposures

Class H Mammals:
185 dB SPL as behavioral threshold for short exposure
Reduce threshold by 3-6 dB for long or multiple exposures

Mid and High-Frequency Noise (> 1000 Hz)

Class L Mammals:
180 (re 1 μPa) dB SPL as behavioral threshold for short exposure.
Reduce threshold by 3-6 dB for long or multiple exposures

Class H Mammals:
180 dB SPL as behavioral threshold for short exposure
Reduce threshold by 3-6 dB for long or multiple exposures

As a tradeoff, consider also the use of a TTS criterion for Class H animals, starting at 190 dB (re 1 μPa) for a 1 second exposure and reducing it by 17 log (time).

Note that there are very few cases in which non-impulsive noise from aircraft could generate levels in the water great enough to cause concern for harassment. On the other hand, if the NMFS '70 dB rule' were to be applied (NRC, 1996), thresholds of order 110 to 130 dB (re 1 μPa) would not be uncommon, and harassment a real possibility.

6.0 THRESHOLDS FOR IMPACT OF UNDERWATER NOISE ON SEA TURTLES

6.1 IMPULSIVE NOISE

For recently approved compliance documents, the thresholds of Young (1991) and Klima et al. (1988) are most often used for injury (see Appendix G). The peak pressure thresholds are all based on the same data, and are consistent. Range thresholds are for ideal conditions and explosives.

Criteria & Thresholds for Injury and TTS for Single Impulsive Noise Event - Sea Turtles

Effect	Turtle Size	Metric	Threshold	Reference
50% Lethal	Large	Peak Pressure	150 psi (241 dB [a])	Klima (88)
50% Lethal	Small	Peak Pressure	20 psi (223 dB [a])	Klima (88)
'safe'	Large	Peak Pressure	50 psi (231 dB [a])	Klima (88)
'safe'	Small	Peak Pressure	5 psi (211 dB [a])	Klima (88)
'safe'	N/A	Range	200 $W^{1/3}$ feet [c]	O'Keeffe and Young (84)
'safe'	N/A	Range	560 $W^{1/3}$ feet [c]	Young (91)
'safe'	N/A	Peak Pressure [b]	50 psi (231 dB [a])	O'Keeffe and Young (84) [b]
'safe'	**N/A**	**Peak Pressure [b]**	**15 psi (221 dB [a])**	**Young (91) [b]**
Injury (except TTS)	N/A	Range	560 $W^{1/3}$ feet [c] Young (1991)	SEAWOLF FEIS (1998), NAWC (1993)
TTS	**N/A**	**Greatest EFD[d] Level in 1/3 Octave Band above 100 Hz**	**182 dB (re 1 μPa^2-s)**	**SEAWOLF FEIS (1998)**

[a] dB re 1 μPa
[b] Peak Pressure metric deduced from range metric using similarity formula for explosive.
[c] This formula designed for explosives, where W is charge weight in pounds
[d] EFD is energy flux density

Note that the harassment threshold used in the SEAWOLF FEIS is for TTS and is the same as that used for odontocetes (except sperm whales). Bold-faced entries in the table are the thresholds used in SEAWOLF, and the ones used in most Navy risk assessments involving explosives. Note also that an 'equivalent' threshold, as discussed in Appendix G, is a peak pressure of 15 psi (221 dB).

6.2 NON-IMPULSIVE NOISE

Non-impulsive noise is not known to cause non-auditory physical damage to sea turtles. The shock waves and large peak pressures of some impulsive sources are not found in continuous signals. There have been no controlled measurements to determine PTS or other physical injuries to sea

turtles from non-impulsive noise. Note, however, that adverse physical effects are suspected for human divers exposed to low-frequency tones (below about 1000 Hz). These effects include possible lung resonance vibrations and inner ear disturbances. Whether or not marine animals suffer similar effects is not known.

ATOC (1995) and the SURTASS-LFA (1999) have addressed the possibility of non-auditory injury to marine life from low-frequency sound.

For lack of better information, risk assessments of the past have usually applied the same harassment threshold to sea turtles as is applied to marine mammals (particularly baleen whales, since the few measurements of sea turtle hearing suggest best sensitivity in the band below 1000 Hz).

7.0 UNDERWATER NOISE IMPACT ON BIRDS AND FISH

7.1 IMPULSIVE NOISE

The principal sources cited in compliance documents for effects of explosive energy on fish, birds and invertebrates are Yelverton et al. (1973, 1981) and Young et al. (1992b).

Mortality and injury tables for impulsive sound have been established by experiment, and are given in terms of two metrics: peak pressure and positive impulse (Yelverton et al, 1973 and 1981). These thresholds were derived from tests using explosives and terrestrial animals and fish in water.

Table 7.1-1 below is typical of what has been used in risk assessments. Note that the preferred metrics are positive impulse and peak pressure.

Notice also that the difference in sound strength between 'safe' and 50% lethal is typically a factor of three to five (in pressure or impulse). This amounts to a difference of only 10 to 15 dB. Note also that Yelverton (1981) recommends a "safe" exposure level for all but the smallest marine animals of 5 psi-ms (the same as for a small fish or diving bird). The thresholds listed have been used in Navy and Air Force compliance documents for impulsive sources. Table 7.1-2 shows references.

Table 7.1-1. Thresholds for Mortal and 'Safe' Exposures to Impulsive Noise for Fish, Birds, Shrimp, Crabs

MARINE ANIMAL	METRIC	50% MORTALITY	'SAFE' STRENGTH
Bird on Water Surface	Positive Impulse	130-150 psi-ms (900-1035 Pa-s)	30 psi-ms (207 Pa-s)
Diving Bird	Positive Impulse	45 psi-ms (310 Pa-s)	6 psi-ms (41 Pa-s)
Shrimp and Crabs	Peak Pressure	50-200 psi (231-243 dB re 1 μPa)	15 psi (221dB re 1 μPa)
Fish (100 g)	**Positive Impulse**	**20 psi-ms (138 Pa-s)**	**5 psi-ms (35 Pa-s)**
Fish (1000 g)	Positive Impulse	50 psi-ms (345 Pa-s)	10 psi-ms (69 Pa-s)

Table 7.1-2 Historical References for Criteria and Thresholds for Physical Injury Caused By An Explosive Sound Source For A Single Event - Fish, Birds, Shrimp, Crabs

Effect	Marine animal	Metric(s)	Threshold(s)	Reference
50% Lethal	Shrimp, Crabs	Peak Pressure	50 to 200 psi (231 to 243 dB*)	Yelverton (1981)
'safe'	**Mammals, Fish, Birds, Turtles, Some Invertebrates**	**Peak Pressure and Positive Impulse**	**5 psi (211 dB*) and 5 psi-ms**	**Young (91), Goertner (82)**
50% Lethal	Fish (0.1 kg)	Positive Impulse	20 psi-ms	Yelverton (1981)
50% Lethal	Fish (1 kg)	Positive Impulse	50 psi-ms	Yelverton (1981)
50% Lethal	Diving Bird	Positive Impulse	45 psi-ms	Yelverton (1981)
'safe'	Diving Bird	Positive Impulse	6 psi-ms	Yelverton (1981)

* dB re 1 μPa

Perhaps most important is the estimate of 'safe' (from physical injury) positive impulse for birds, small turtles, small fish, and all marine mammals of 5 psi-ms [derived by Young (1991) from Yelverton (1981)]. The corresponding 'safe' impulse for human divers is 2 psi-ms (Christian and Gaspin, 1974). Unfortunately, the interpretation and calculation or measurement of positive impulse is not necessarily straightforward for impulsive sounds that do not have the characteristic waveform of an explosive in a free field. Propagation effects (such as multipath) and different waveforms (e.g., N waves of sonic booms) are examples.

7.2 NON-IMPULSIVE NOISE

Non-impulsive noise is not known to cause non-auditory physical damage to marine animals. There is no agreed-upon threshold for physical injury to sea birds or fish by non-impulsive noise. In fact, most risk assessments do not consider the possibility.

Injury and harassment of protected sea birds and fish by projectors has been estimated in several compliance documents (including ATOC, 1995). A level of 240 dB (re 1 μPa) for a short (few seconds) pulse is consistent with the past thresholds for injury.

8.0 IN-AIR NOISE & MARINE ANIMALS - NOTES ON THRESHOLDS FOR ADVERSE EFFECTS

Just as in water, high sound levels in the atmosphere can cause adverse effects on marine animals. The usual situation is one of airborne explosives or aircraft (including missiles and rockets) causing sound levels great enough to injure animals not fully submerged in water (the submerged case being included in the previous section). Especially vulnerable are pinnipeds (seals and sea lions) under haul-out conditions, as well as sea birds.
Risks of injury or harassment from noise in air to animals which spend most of their lives with "ears" underwater (whales, dolphins, manatees, dugongs, sea turtles) are judged to be very small. There is thus little interest in and little known about the effects of noise in air on cetaceans, sirenians, sea turtles, or fish..

8.1 RISKS TO PINNIPEDS

Perhaps the key factor in estimating possible injury or harassment of pinnipeds from airborne noise is the hearing sensitivity. Measured hearing thresholds (see, e.g., Richardson et al, 1995) are found to be best in the frequency range above 2000 Hz and to be somewhat less than human sensitivities. In the low bands, seals and most sea lions are nearly deaf (an exception is the California sea lion). Since most aircraft noise is concentrated in the low bands, especially sonic booms, there is a lower chance of significant hearing damage for most pinnipeds. On the other hand, aircraft noise that causes serious disturbance to a haul-out site has been cited in the past as harassment. Effects of concern include panic, abandonment of pups, stampeding, etc.

Sonic boom noises on the order of 80 to 90 dB (SPL, re 20 μPa) have been known to startle seals.

Francine and Stewart (1995) analyzed effects on pinnipeds at San Miguel Island from a sonic boom caused by a rocket launch in 1991 at Vandenberg Air Force Base. Peak overpressures measured near the seal haul-out sites were on the order of 60 to 90 Pa (130 to 134 dB re 20 μPa.). Although the observed shock wave was not of classic form, most of the energy was in the low band (<500 Hz), as expected. Hence, observed unweighted SEL was about 125 dB, while A-weighted SEL was near 80 dB.

Bowles (1995) notes the lack of panic attacks for sonic boom peak pressures as high as 150 dB (re 20 μPa).

8.2 EXTRAPOLATION FROM HUMAN AND LABORATORY ANIMAL EFFECTS

Although there are a number of reports and published studies on the effects of aircraft noise on marine animals in air (see the reference list for a sample), there are few attempts to quantify the relationship between a noise metric and a well-defined injury or harassment criterion. Bowles (1995) suggests the application of results of sonic boom studies on humans and laboratory animals to marine mammals, but acknowledges that there may be little scientific basis for the approach.

She notes that "Dose-effect models have not been developed..." and that the relationship between avoidance and panic (for pinnipeds) is key.

8.2.1 Impulsive Noise

CHABA recommendations (e.g., Ward, 1968) for humans specifies maximum safe limits of impulsive sounds as follows:

- (i) The maximum peak pressure is 164 dB, for a pulse with duration on the order of 25 micro seconds.
- (ii) Peak pressure level permitted decreases at 2 dB per double duration (about 7log(t)). Terminal level is 138 dB for 0.2 to 1.0 seconds.
- (iii) If the number of exposures per day is not 100, then an adjustment is made to the peak as follows: for 1 pulse, add 15 dB, for 20 add 10 dB, for 50 add 5 dB.

Thus, the "safe" peak-pressure exposure level for a single impulse of duration less than one second is 153 dB (re 20 μPa), or 179 dB (re 1 μPa). This is the sonic boom level referred to by Bowles (1995) as one which did not elicit panic in pinnipeds.

There is evidence that some sea birds are significantly disturbed (if not injured) by impulsive sound levels in air in the 120 dB range (re 1 μPa). It is also observed that humans are annoyed by airplane noise levels near 135 dB. (These two values correspond to about 0.02 and 0.14 psf respectively.)

8.2.2 Continuous Noise

Eldridge and Miller (1969) estimate octave band levels for humans for which TTS will exceed risk criteria. For 1.5 minutes, the octave band levels below 1000 Hz are 135 dB (re 20 μPa). At 3 kHz, the level is about 120 dB. These correspond to spectrum levels of about 125 dB at 10 Hz, 115 dB at 100 Hz, 105 dB at 1000 Hz, and 85 dB at 3 kHz (all re 20 μPa). For 15 minutes of exposure, the TTS threshold levels decrease by about 20 dB. The most logical interpretation is that an SPL of 135 dB (re 20 μPa) for frequencies below 1000 Hz or an SPL of 120 dB near 3000 Hz is sufficient to cause TTS for exposure times near 1.5 minutes.

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9.3 LIST OF ACRONYMS

ACOMMS	Advanced Acoustics Communications
AFRL	Air Force Research Laboratory

ALFS	Airborne Low Frequency Sonar
ARPA	Advanced Research Projects Agency
ASTO	Advanced Systems Technology Office
ASW	Antisubmarine Warfare
ATOC	Acoustic Thermometry for Ocean Climate
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CNO	Chief of Naval Operations
CZMA	Coastal Zone Management Act
CZMA	Coastal Zone Management Act
DARPA	Defense Advanced Research Projects Agency
dB	decibel
dB	Decibel
dB(A)	A-Weighted Decibel Scale
DDG	Guided Missile Destroyer
DoD	Department of Defense
DoN	Department of the Navy
DRC	Damage Risk Criterion
EA	Environmental Assessment
EFD	Energy Flux Density
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EO	Executive Order
ER	Environmental Review
ESA	Endangered Species Act
FEIS	Final Environmental Impact Statement
ft	Foot or Feet
FY	Fiscal Year
HIFT	Heard Island Feasibility Test
Hz	hertz
IHA	Incidental Harassment Authorization
in	Inch(es)
kHz	kilohertz
km	kilometer
km^2	square kilometers
kt	knot(s)
LF	Low Frequency
LFA	Low-Frequency Active
LOA	Letter of Authorization (for Incidental Harassment)
LVBDS	Lightweight Broadband Variable – Depth Sonar
LWAD	Littoral Warfare Advanced Development
LWAD	Littoral Warfare Advanced Development
μPa	micropascal
m	meter
MMPA	Marine Mammal Protection Act
MMRP	Marine Mammal Research Program

MMS	Mineral Management Service
mph	miles per hour
MTTS	Masked Temporary Threshold Shift
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
nm	Nautical Mile(s)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
NSWC	Naval Surface Warfare Center
NUWC	Naval Undersea Warfare Center
OEA	Overseas Environmental Assessment
OEIS	Overseas Environmental Impact Statement
Pa	pascal
PEO (USW)	Program Executive Office Undersea Warfare
PMA	Program Manager Air
PMRF	Pacific Missile Range Facility
psf	pounds per square foot
psi	pounds per square inch
PTS	Permanent Threshold Shift
R	Range
RDT&E	Research, Development, Testing, and Evaluation
re	Referenced To
RONA	Record of Non-Applicability
s	second(s)
SAIC	Science Applications International Corporation
SEL	Sound Exposure Level
SL	Source Level
SPL	Sound Pressure Level
SURTASS	Surveillance Towed Array Sonar System
TL	Transmission Loss
TTS	Temporary Threshold Shift
USC	United States Code
USFWS	United States Fish and Wildlife Service
USS	United States Ship
USW	Undersea Warfare
VA	Virginia
ZOI	Zone of Influence

APPENDIX A.
SUMMARY OF SELECTED LAWS, EXECUTIVE ORDERS, AND REGULATIONS

A.1 LAWS

7 COASTAL ZONE MANAGEMENT ACT OF 1972 (CZMA), 16 U.S.C. 1451 et seq.

Provides incentives for coastal States to develop and implement coastal area management programs. Plays a significant role in water pollution abatement, particularly with regard to nonpoint source pollution. State coastal zone management programs frequently incorporate flood control, sediment control, grading control, and storm water runoff control statutes. Federal actions that impact the coastal zone must be consistent to the maximum extent practicable with the State program.

11 DEFENSE APPROPRIATIONS ACT OF 1991.

Establishes the Legacy Resource Management Program for the stewardship of biological, geophysical, cultural and historic resources on DoD lands.

13 ENDANGERED SPECIES ACT OF 1973 (ESA), 16 U.S.C. 1531 et seq.

Provides for listing of endangered and threatened species of plants and animals, and designation of critical habitat for animal species. Establishes federal policy that federal agencies, in exercise of their authorities, shall seek to conserve endangered species. Prohibits federal agencies from taking any action that would adversely affect any endangered or threatened species, or critical habitat. Establishes a consultation process involving federal agencies generally and federal wildlife management agencies, to facilitate avoidance of agency action that would adversely affect species or habitat. Prohibits all persons subject to U.S. jurisdiction including federal agencies, from "taking" endangered species. Taking prohibition includes any harm or harassment, and applies within the U.S. and on the high seas.

19 FISH AND WILDLIFE CONSERVATION ACT OF 1980, 16 U.S.C 2901 et seq.

Provides for conservation, protection, restoration, and propagation of certain species; including migratory birds threatened with extinction.

23 MARINE MAMMAL PROTECTION ACT OF 1972 (MMPA), 16 U.S.C. 1431 et seq.

Subject to limited exceptions, prohibits the "taking" of marine mammals in the United States or on the high seas. "Taking" includes any harm or harassment.

24 MARINE PROTECTION, RESEARCH, AND SANCTUARIES ACT, 33 U.S.C. 1401.

Implements for the United States the London Dumping Convention. Requires EPA permit for

transportation from the U.S., or from elsewhere in the world, of any "material" for the purpose of disposing of it in the ocean. Establishes the National Marine Sanctuary program, under which the National Oceanic and Atmospheric Administration (NOAA) designates and establishes regulations pertaining to national marine sanctuaries. NOAA regulations in some cases restrict discharges from vessels and aircraft overflight.

25 MIGRATORY BIRD TREATY ACT, 16 U.S.C. 703.

Prohibits taking or harming of migratory and certain other birds, their eggs, nests, or young without the appropriate permit.

28 NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (NEPA), 42 U.S.C. 4321 et seq.

Mandates federal agency consideration and documentation of environmental impacts of proposed actions and legislation. Mandates preparation of comprehensive environmental impact statement where proposed action is "major" and significantly affects the quality of the human environment.

30 NOISE CONTROL ACT OF 1972, 42 U.S.C. 4901 et seq (as amended by the Quiet Communities Act).

Authorizes establishment of Federal noise emission standards for products distributed in commerce, and coordinates Federal research efforts in noise control.

A.2 CODE OF FEDERAL REGULATIONS

The Code of Federal Regulations (CFR) consists of 50 titles representing broad areas subject to Federal regulation. All general and permanent regulations published in the daily Federal Resister by executive agencies and departments of the Federal government appear in the CFR, which is updated annually. For example, all regulations issued by the EPA under the subject heading "Protection of the Environment" are codified in Title 40 of the CFR.

Relevant CFRs include:

1. 15 CFR 923, National Oceanic and Atmospheric Administration Coastal Zone Management Program Development and Approval Regulation;

2. 15 CFR 930, Federal Consistency with Approved Coastal Management Programs;

13. 40 CFR 6, EPA Regulations on Implementation of National Environmental Policy Act Procedures;

90. 50 CFR 10, Regulations Concerning Marine Mammals;

91. 50 CFR 10.13, List of Migratory Birds;

92. 50 CFR 17.11 and 17.12, Fish and Wildlife Service List of Endangered and Threatened Wildlife;

93. 50 CFR 18, 216, 228, Regulations Concerning Marine Mammals;

94. 50 CFR 402, Interagency Cooperation - Endangered Species Act of 1973.

A.3 EXECUTIVE ORDERS (EOS)

3 EXECUTIVE ORDER 12088, of 13 October 1978, Federal Compliance with Pollution Control Standards.

Provides that the head of each federal agency is responsible for compliance with "applicable pollution control standards," defined as "the same substantive, procedural and other requirements that would apply to a private person." Requires federal agencies to cooperate with the U.S. EPA, States, and local agencies in the prevention, control and abatement of environmental pollution. Requires the EPA Administrator to provide technical advice and assistance to Executive agencies in order to ensure their cost effective and timely compliance with applicable pollution control standards. Provides that disputes between the U.S. EPA and another federal agency regarding environmental violations shall be elevated to the Office of Management and Budget for resolution.

4 EXECUTIVE ORDER 12114, 4 January 1979, Environmental Effects Abroad of Major Federal Actions.

Requires environmental study, under delineated circumstances, of actions proposed to be undertaken outside the geographical borders of the United States.

A.4 INCIDENTAL HARASSMENT AUTHORIZATION UNDER MMPA

[excerpts from: NOAA/NMFS (**1998**). “Small Takes of Marine Mammals Incidental to Specified Activities; Explosives Testing at Eglin Air Force Base, FL,” National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA) Federal Register: Volume 63, Number 235, Page 67669-67672, December 8, 1998]

Section 101(a)(5)(A) of the MMPA (16 U.S.C. 1361 et seq.) directs the Secretary of Commerce to allow, upon request, the incidental, but not intentional, taking of marine mammals by U.S. citizens who engage in a specified activity (other than commercial fishing) within a specified geographical region if certain findings are made and regulations are issued.

Permission may be granted if NMFS finds that the taking will have a negligible impact on the species or stock(s) and will not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses and that the permissible methods of taking and

requirements pertaining to the monitoring and reporting of such taking are set forth. NMFS has defined ''negligible impact" in 50 CFR 216.103 as ''...an impact resulting from the specified activity that cannot be reasonably expected to, and is not reasonably likely to, adversely affect the species or stock through effects on annual rates of recruitment or survival."

Subsection 101(a)(5)(D) of the MMPA established an expedited process by which U.S. citizens can apply for an authorization to incidentally take small numbers of marine mammals by harassment for a period of up to 1 year. The MMPA defines ''harassment" as: ...any act of pursuit, torment, or annoyance which (a) has the potential to injure a marine mammal or marine mammal stock in the wild; or (b) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.

Specific definitions of small numbers and negligible impact for IHA(applied to Eglin AFB Explosives Tests)

Interim regulations implementing subsection 101(a)(5)(D) of the MMPA were issued on April 10, 1996 (61 FR 15884). These regulations contain specific definitions to interpret Congressional meaning of the terms ''small numbers" and ''negligible impact." For the purposes of this part, ''small numbers" means a portion of a marine mammal species or stock whose taking would have a negligible impact on that species or stock. ''Negligible impact" is an impact resulting from the specified activity that cannot be reasonably expected to, and is not reasonably likely to, adversely affect the species or stock through effects on annual rates of recruitment or survival. Because, due to mitigation measures required under IHA, no marine mammals are likely to be killed or seriously injured by the proposed activities, harassment takings are expected to be reduced to the lowest level practicable, the number of authorized takings is considered small, and the takings have no more than a negligible impact on the affected species and stocks of marine mammals.

APPENDIX B.
SOME CONVERSION TABLES

The tables which follow are included to provide the reader with a reference for converting among the various sets of units used in acoustics. The fourth report in this series contains a comprehensive collection of definitions, defining equations, and conversion tables.

Pressure (Force/Area)

1 Pa = 1 N/m^2 = 10^6 μ Pa = 10 dyn/cm^2 = 10 μbar
1 psi = 144 psf = 6.895·10^9 μPa = 3.447·10^8 (20 μPa)
1 psi = 6.895 kPa = 0.068 atm
1 psf = 0.00694 psi = 4.758·10^7 μPa
1 atm = 1.014 bar = 14.7097 psi = 2118.2 psf = 1.014·10^{11} μPa
1 kPa = 1000 Pa = 10^9 μPa = 0.0145 psi = 20.88 psf
1 μPa = 0.05·(20 μPa) = 10^{-5} dyn/cm^2 = 1.45 ·10^{-10} psi
20 μPa = 0.0002 μbar = 2.9 ·10^{-9} psi
1 μbar = 0.1 Pa = 1 dyn/cm^2
0.0002 μbar = 0.0002 dyn/cm^2 = 20 μPa

Sound Pressure Level

X dB (re 1 μPa) = (X - 26) dB (re 20μPa) = (X-100) dB (re 1 μbar)

Example: 200 dB = 174 dB (re 20μPa) = 100 dB (re 1 μbar)

Y dB (re 20μPa) = (Y+26) dB (re 1 μPa) = (Y - 171) dB (re 1 psi)
= (Y - 221) dB (re 1 psf)

For a pressure of 1 psi,

SPL = 0 dB (re 1 psi)
= 197 dB (re 1 μPa)
= 171 dB (re 20 μPa)

Acoustic Impedance (Density x Sound-Speed) **For Water:**

$\rho_w \approx 1$ g/cm^3 = 10^3 kg/m^3 $\qquad$ $c_w \approx 1.5 \cdot 10^3$ m/s = $1.5 \cdot 10^5$ cm/s

Then, $\rho_w c_w \approx 1.5 \cdot 10^6$ kg/s·m^2 = $1.5 \cdot 10^6$ rayl = $1.5 \cdot 10^5$ g/s·cm^2
= $1.5 \cdot 10^{12}$ μPa·(s/m) = $1.5 \cdot 10^5$ (dyn/cm^2)(s/cm)
= $3.07155 \cdot 10^5$ psf/s = $213.3 \cdot 10^3$ psi/s

Acoustic Impedance For Air:

$\rho_a \approx 0.00129$ g/cm^3 = 1.225 kg/m^3 $\qquad c_a \approx 344$ m/s = $3.44 \cdot 10^4$ cm/s

Then, $\rho_a c_a \approx 421.4$ kg/s·m^2 = 421.4 rayl = 42.14 (dyn/cm^2)·(s/cm)
= 86.804 psf/s = 0.0603 psi/s = $4.214 \cdot 10^8$ μPa·(s/m)

Comparison Of Impedances

$c_w / c_a \approx 4.36$
$\rho_w / \rho_a \approx 816$

Impedance for Water/ Impedance for Air = $\rho_w c_w / \rho_a c_a \approx 3560$

$10 \log (\rho_w c_w / \rho_a c_a) \approx 10 \log (3560) \approx 35.5$ dB

Acoustic Intensity (Pressure^2/Impedance)

1 W/m^2 = 1 J/(s·m^2) = 1 N/m·s = 1 Pa·(m/s) = 10^6 μPa·(m/s)

For plane or spherical waves,

Pressure (rms)	Intensity In Water	Intensity In Air
1 μPa	$6.7 \cdot 10^{-19}$ W/m^2	$2.3 \cdot 10^{-15}$ W/m^2
1 μbar = 0.1 Pa	$6.7 \cdot 10^{-9}$ W/m^2	$2.3 \cdot 10^{-5}$ W/m^2
20 μPa = 0.0002 μbar	$2.7 \cdot 10^{-16}$ W/m^2	$9.6 \cdot 10^{-13}$ W/m^2
$1.2 \cdot 10^3$ μPa = 60· (20μPa)	$9.6 \cdot 10^{-13}$ W/m^2	
$1.7 \cdot 10^{-2}$ μPa = (1/60) μPa		$6.7 \cdot 10^{-19}$ W/m^2
1 psi = 6.895 kPa	31.8 W/m^2	$1.14 \cdot 10^5$ W/m^2
1 psf = 0.0069 psi	0.0015 W/m^2	5.50 W/m^2

For a given pressure, the intensity in air is about 3600 times the intensity in water.
To achieve a given intensity in water requires about 60 times as much pressure as is required to achieve that same intensity in air (noting that 60^2 is about 3600).

Positive (Acoustic) Impulse (Pressure·Time)

Positive Impulse is defined for impulsive signals as the time integral of the pressure over the first, positive phase of the pressure.

$1\ psi \cdot ms = 1000\ psi \cdot \mu s$
$1\ psi \cdot s = 1000\ psi \cdot ms = 6895\ Pa \cdot s$
$1\ kPa \cdot s = 10^9\ \mu Pa \cdot s = 10^{12}\ \mu Pa \cdot ms$
$1\ kPa \cdot ms = 10^6\ \mu Pa \cdot s$
$1\ psi \cdot ms = 144\ psf \cdot ms$
$1\ psi \cdot s = 6.895\ kPa \cdot s$
$1\ psi \cdot ms = 6.895\ Pa \cdot s$

Energy Flux Density (Units of [Pressure ^{2} Time]/Impedance or Intensity ·Time)

$1\ W \cdot s/m^2 = 1\ J/m^2 = 1 N/m = 1\ Pa \cdot m = 10^6\ \mu Pa \cdot m$

Energy (Flux Density) Level

X dB re $1\ \mu Pa^2 \cdot s = (X + 26)$ dB re $20\ \mu Pa^2 \cdot s = (X + 154)$ dB re $1 psi^2 \cdot s$

X dB re $1\ erg/cm^2 = (X + 52)$ dB re $(1\ dyn/cm^2)^2\ s$

Y dB re $1\ erg/cm^2 = (Y + 152)$ dB re $1\ \mu Pa^2\ s$

Z dB re $(1\ dyn/cm^2)^2 = (Z + 100)$ dB re $1\ \mu Pa^2\ s$

APPENDIX C
STATUS AND CLASSIFICATION OF MARINE MAMMALS AND SEA TURTLES

REASON FOR THIS APPENDIX

Certain marine animals are protected by federal laws – most important for this report the marine mammals and certain sea turtles. This appendix lists the endangered/threatened status for each species.

Also, It is clear from the above discussion that thresholds and criteria for injury and harassment of marine animals are usually specific to order, and sometimes to family or individual species. This appendix provides a list of the names (both common and scientific) for these orders, families and species.

The most logical way to organize these lists is by standard biological classification. The next subsection provides a partial overview of marine animals by phylum and sub-phylum, class and sub-class, order and sub-order, to the level of family. This helps to distinguish fish, reptiles, crustaceans, mammals, etc.

The subsequent subsection focuses on marine mammal and sea turtle species, giving both names and protected status. All of this information is periodically published by the regulators (DOC/NOAA/NMFS and DOI/USFWLS).

C.1 CLASSIFICATION (PARTIAL LIST)

I. Phylum Level (Partial List)

Phylum Arthropoda
  Sub-Phylum Crustacea
    Class malacostraca (*krill, crabs, shrimp, ...*)
    Class insecta
    ....
  Sub-Phylum Chelicerata
    Class merostomata (*hoseshoe crabs, ...*)
Phylum Echinocermata
    Class asteroidea (*starfish*)
    ......

Phylum Cnidaria (*jellyfish, corals, hydra, sea anemones,...*)

Phylum Mollusca

Phylum Chordata
Sub-Phylum Vertebrata
Class reptilia (*reptiles*)
Order testudines (turtles)
Subclass crocodylia
Subclass squamata (*snakes, lizards*)

(Sub)Class aves (*birds*)

Class lissamphibia (*frogs, ...*)

Class chondrichthyes (*sharks, rays, ...*)

Class actinopterygii (*fish*)

Class mammilia (*mammals*)

Class reptilia (*reptiles*)

Class .....

II. Marine Mammals (Phylum: chordata, Sub-Phylum: vertebrata, Class: Mammilia)

Class: mammalia (*mammals*)
- All mammals are vertebrates, have mammary glands, have hair or blubber, and have three middle-ear bones.
- There are 20 Orders of mammals, and 10 million species.
- Three of the 20 Orders contain all of the marine mammals (as defined in the Marine Mammal Protection Act): Order cetacea, Order carnivora, and Order sirenia.

Order: cetacia (*whales, dolphins, porpoises*)
Sub-Order mysticeti (*baleen whales or mysticetes*)
FAMILIES: 4
SPECIES: 11, including *blue, fin, sei, Bryde's, minke, gray, right, humpback, bowhead*
Sub-Order odontoceti (*toothed whales or odontocetes*)
FAMILIES/SUPER-FAMILIES: 6
SPECIES: 68, including *sperm whale, beaked whales, killer whales, dolphins and porpoises*

Order: carnivora (*carnivores*)
FAMILY mustelidae (*weasel, skunk, ...*)
SUB-FAMILY: lutrinae (*otter*)
SPECIES: *sea otters*

FAMILY ursidae (*bear*)
SPECIES: *polar bear*

Sub-Order: **pinnipedia** (aquatic carnivores with all limbs modified into flippers)
FAMILY phocidae (*hair seals*)
FAMILY otariidae (*eared seals: fur seal and sea lions*)
FAMILY odobenidae (*walrus*)

Order sirenia (***manatees and dugongs***)
FAMILIES: (2) *manatees and dugongs*
SPECIES: 3 *manatees* and 1 *dugong*

III. Sea Turtles (Phylum: chordata, Sub-Phylum: vertebrata)

Class reptilia (*reptiles*)
Order testudines (turtles)

C.2 MARINE MAMMAL LISTS

ORDER CETACEA – SUBORDER MYSTICETI (BALEEN WHALES)

Common Name	Scientific Name	Status under ESA/MMPA
Blue Whale	*Balaenoptera musculus*	Endangered (ESA)
Bowhead Whale	*Balaena mysticetus*	Endangered (ESA)
Bowhead Whale (Western Arctic Stock)	*Balaena mysticetus*	Endangered (ESA)
Bryde's Whale	*Balaenoptera edeni*	No Special Status
Fin Whale (Finback Whale)	*Balaenoptera physalus*	Endangered (ESA)
Fin Whale (Alaska Stock)	*Balaenoptera physalus*	Endangered (ESA)
Gray Whale	*Eschrichtius robustus*	Recovered* (ESA)
Gray Whale (Eastern North Pacific Stock)	*Eschrichtius robustus*	Recovered* (ESA)
Humpback Whale	*Megaptera novaeangliae*	Endangered (ESA)
Humpback Whale (Western North Pacific Stock)	*Megaptera novaeangliae*	Endangered (ESA)
Humpback Whale (Central North Pacific Stock)	*Megaptera novaeangliae*	Endangered (ESA)
Minke Whale	*Balaenoptera acutorostrata*	No Special Status
Minke Whale (Alaska Stock)	*Balaenoptera acutorostrata*	No Special Status
Northern Right Whale	*Eubalaena glacialis*	Endangered (ESA)
Northern Right Whale (North Pacific Stock)	*Eubalaena glacialis*	Endangered (ESA)
Sei Whale	*Balaenoptera borealis*	Endangered (ESA)

CETACEA – ODONTOCETI - MEDIUM TO LARGE SIZE TOOTHED WHALES

Common Name	Scientific Name	Status under ESA/MMPA
Andrew's Beaked Whale	*Mesoplodon bowdoini*	No Special Status
Arnoux's Beaked Whale	*Berardius arnuxii*	No Special Status
Baird's Beaked Whale	*Berardius bairdii*	No Special Status
Baird's Beaked Whale (Alaska Stock)	*Berardius bairdii*	No Special Status
Beluga	*Delphinapterus leucas*	No Special Status
Beluga (Beaufort Sea Stock)	*Delphinapterus leucas*	No Special Status
Beluga (Eastern Chukchi Sea Stock)	*Delphinapterus leucas*	No Special Status
Beluga (Norton Sound Stock)	*Delphinapterus leucas*	No Special Status
Beluga (Bristol Bay Stock)	*Delphinapterus leucas*	No Special Status

Beluga (Cook Inlet Stock)	*Delphinapterus leucas*	No Special Status
Blainville's Beaked Whale	*Mesoplodon densirostris*	No Special Status
Cuvier's Beaked Whale	*Ziphius cavirostris*	No Special Status
Cuvier's Beaked Whale (Alaska Stock)	*Ziphius cavirostris*	No Special Status
Dense Beaked Whale	*Mesoplodon densirostris*	No Special Status
Dwarf Sperm Whale	*Kogia simus*	No Special Status
False Killer Whale	*Pseudorca crassidens*	No Special Status
Gervais' Beaked Whale	*Mesoplodon europaeus*	No Special Status
Ginkgo-toothed Beaked Whale	*Mesoplodon ginkgodens*	No Special Status
Gray's Beaked Whale	*Mesoplodon grayi*	No Special Status
Gulf Stream Beaked Whale	*Mesoplodon europaeus*	No Special Status
Hector's Beaked Whale	*Mesoplodon hectori*	No Special Status
Hubbs' Beaked Whale	*Mesoplodon carlhubbsi*	No Special Status
Killer Whale	*Orcinus orca*	No Special Status
Killer Whale (Alaska Resident Stock)	*Orcinus orca*	No Special Status
Killer Whale (Alaska Transient Stock)	*Orcinus orca*	No Special Status
Long-finned Pilot Whale	*Globicephala melaena (melas)*	No Special Status
Longman's Beaked Whale	*Mesoplodon (Indopacetus) pacificus*	No Special Status
Melon-headed Whale	*Peponocephala electra*	No Special Status
Narwhal	*Monodon monoceros*	No Special Status
Northern Bottlenose Whale	*Hyperoodon ampullatus*	No Special Status
Orca	*Orcinus orca*	No Special Status
Orca (Alaska Resident Stock)	*Orcinus orca*	No Special Status
Orca (Alaska Transient Stock)	*Orcinus orca*	No Special Status
Pygmy Beaked Whale	*Mesoplodon peruvianus*	No Special Status
Pygmy Killer Whale	*Feresa attenuata*	No Special Status
Pygmy Right Whale	*Caperea marginata*	No Special Status
Pygmy Sperm Whale	*Kogia breviceps*	No Special Status
Shepherd's Beaked Whale	*Tasmacetus shepherdi*	No Special Status
Short-finned Pilot Whale	*Globicephala macrorhynchus*	No Special Status
Southern Bottlenose Whale	*Hyperoodon planifrons*	No Special Status
Southern Right Whale	*Eubalaena australis*	Endangered (ESA)
Sowerby's Beaked Whale	*Mesoplodon bidens*	No Special Status
Sperm Whale	*Physeter macrocephalus (catodon)*	Endangered (ESA)
Sperm Whale (Alaska	*Physeter macrocephalus*	Endangered (ESA)

Stock)	*(catodon)*	
Stejneger's Beaked Whale	*Mesoplodon stejnegeri*	No Special Status
Stejneger's Beaked Whale (Alaska Stock)	*Mesoplodon stejnegeri*	No Special Status
Strap-toothed Whale	*Mesoplodon layardii*	No Special Status
True's Beaked Whale	*Mesoplodon mirus*	No Special Status
White Whale	*Delphinapterus leucas*	No Special Status

* Note: Recovered is not an official designation under the ESA. The Gray Whale was removed from the list of endangered and threatened species in June, 1995

CETACEA - ODONTOCETI - DOLPHINS

Common Name	Scientific Name	Status under ESA/MMPA
Amazon River Dolphin	*Inia geoffrensis*	No Special Status
Atlantic Humpbacked Dolphin	*Sousa teuszii*	No Special Status
Atlantic Spotted Dolphin	*Stenella frontalis*	No Special Status
Atlantic White-sided Dolphin	*Lagenorhynchus acutus*	No Special Status
Beiji	*Lipotes vexillifer*	Endangered (ESA)
Black Dolphin	*Cephalorhynchus eutropia*	No Special Status
Boto	*Inia geoffrensis*	No Special Status
Bottlenose Dolphin	*Tursiops truncatus*	No Special Status
Bottlenose Dolphin (Mid-Atlantic Coastal Migratory)	*Tursiops truncatus*	Depleted (MMPA)
Chinese River Dolphin	*Lipotes vexillifer*	Endangered (ESA)
Clymene Dolphin	*Stenella clymene*	No Special Status
Cochito	*Phocoena sinus*	Endangered (ESA)
Commerson's Dolphin	*Cephalorhynchus commersonii*	No Special Status
Common Dolphin	*Delphinus delphis*	No Special Status
Dusky Dolphin	*Lagenorhynchus obscurus*	No Special Status
Franciscana	*Pontoporia blainvillei*	No Special Status
Fraser's Dolphin	*Lagenodelphis hosei*	No Special Status
Ganges River Dolphin	*Platanista gangetica*	No Special Status
Heaviside's Dolphin	*Cephalorhynchus heavisidii*	No Special Status
Hector's Dolphin	*Cephalorhynchus hectori*	No Special Status
Hourglass Dolphin	*Lagenorhynchus cruciger*	No Special Status
Indo-pacific Humpbacked Dolphin	*Sousa chinensis*	No Special Status
Indus River Dolphin	*Platanista minor*	No Special Status
Irrawaddy Dolphin	*Orcaella brevirostris*	No Special Status
Killer Whale	*Orcinus orca*	No Special Status

Killer Whale (Alaska Resident Stock)	*Orcinus orca*	No Special Status
Killer Whale (Alaska Transient Stock)	*Orcinus orca*	No Special Status
La Plata River Dolphin	*Pontoporia blainvillei*	No Special Status
Northern Right Whale Dolphin	*Lissodelphis borealis*	No Special Status
Orca	*Orcinus orca*	No Special Status
Orca (Alaska Resident Stock)	*Orcinus orca*	No Special Status
Orca (Alaska Transient Stock)	*Orcinus orca*	No Special Status
Pacific White-sided Dolphin	*Lagenorhynchus obliquidens*	No Special Status
Pacific White-sided Dolphin (Central North Pacific Stock)	*Lagenorhynchus obliquidens*	No Special Status
Pantropical Spotted Dolphin	*Stenella attenuata*	No Special Status
Peale's Dolphin	*Lagenorhynchus australis*	No Special Status
Risso's Dolphin	*Grampus griseus*	No Special Status
Rough-toothed Dolphin	*Steno bredanensis*	No Special Status
Saddleback Dolphin	*Delphinus delphis*	No Special Status
Sarawak Dolphin	*Lagenodelphis hosei*	No Special Status
Short-snouted Spinner Dolp	*Stenella clymene*	No Special Status
Southern Right Whale Dolphin	*Lissodelphis peronii*	No Special Status
Spinner Dolphin	*Stenella longirostris*	No Special Status
Spinner Dolphin (Eastern)	*Stenella longirostris*	Depleted (MMPA)
Streaker	*Stenella coeruleoalba*	No Special Status
Striped Dolphin	*Stenella coeruleoalba*	No Special Status
Tucuxi	*Sotalia fluviatilis*	No Special Status
Vaquita	*Phocoena sinus*	Endangered (ESA)
White-beaked Dolphin	*Lagenorhynchus albirostris*	No Special Status

CETACEA - ODONTOCETI - PORPOISES

Common Name	**Scientific Name**	**Status under ESA/MMPA**
Burmeister's Porpoise	*Phocoena spinipinnis*	No Special Status
Dall's Porpoise	*Phocoenoides dalli*	No Special Status
Dall's Porpoise (Alaska Stock)	*Phocoenoides dalli*	No Special Status
Finless Porpoise	*Neophocaena*	No Special Status

	phocaenoides	
Harbor Porpoise	*Phocoena phocoena*	Proposed For Listing (ESA)
Harbor Porpoise (Alaska Stock)	*Phocoena phocoena*	No Special Status
Spectacled Porpoise	*Australophocaena dioptrica*	No Special Status

PINNIPEDIA – SEA LIONS, WALRUS

Common Name	Scientific Name	Status under ESA/MMPA
Australian Sea Lion	*Neophoca cinerea*	No Special Status
California Sea Lion	*Zalophus californianus*	No Special Status
Hooker's Sea Lion	*Phocarctos hookeri*	No Special Status
New Zealand Sea Lion	*Phocarctos hookeri*	No Special Status
Northern Sea Lion	*Eumetopias jubatus*	Threatened (ESA)
Northern Sea Lion (Western U.S. Stock)	*Eumetopias jubatus*	Threatened (ESA)
Northern Sea Lion (Eastern Stock)	*Eumetopias jubatus*	Threatened (ESA)
South American Sea Lion	*Otaria byronia*	No Special Status
Steller Sea Lion	*Eumetopias jubatus*	Threatened (ESA)
Steller Sea Lion (Western U.S. Stock)	*Eumetopias jubatus*	Endangered (ESA)
Steller Sea Lion (Eastern Stock)	*Eumetopias jubatus*	Threatened (ESA)
Walrus	*Odobenus rosmarus*	No Special Status

PINNIPEDIA - SEALS

Common Name	Scientific Name	Status under ESA/MMPA
Baikal Seal	*Phoca sibirica*	No Special Status
Bearded Seal	*Erignathus barbatus*	No Special Status
Bearded Seal (Alaska Stk)	*Erignathus barbatus*	No Special Status
Bladdernose Seal	*Cystophora cristata*	No Special Status
Caribbean Monk Seal	*Monachus tropicalis*	Endangered (ESA)
Caspian Seal	*Phoca caspica*	No Special Status
Crabeater Seal	*Lobodon carcinophagus*	No Special Status
Greenland Seal	*Phoca groenlandica*	No Special Status
Grey Seal	*Halichoerus grypus*	No Special Status
Harbor Seal	*Phoca vitulina*	No Special Status
Harbor Seal (Southeast Alaska Stock)	*Phoca vitulina*	No Special Status
Harbor Seal (Gulf of Alaska Stock)	*Phoca vitulina*	No Special Status
Harbor Seal (Bering Sea	*Phoca vitulina*	No Special Status

Stock)		
Harp Seal	*Phoca groenlandica*	No Special Status
Hawaiian Monk Seal	*Monachus schauinslandi*	Endangered (ESA)
Hooded Seal	*Cystophora cristata*	No Special Status
Largha Seal	*Phoca largha*	No Special Status
Leopard Seal	*Hydrurga leptonyx*	No Special Status
Mediterranean Monk Seal	*Monachus monachus*	Endangered (ESA)
Northern Elephant Seal	*Mirounga angustirostris*	No Special Status
Ribbon Seal	*Phoca fasciata*	No Special Status
Ribbon Seal (Alaska Stk)	*Phoca fasciata*	No Special Status
Ringed Seal	*Phoca hispida*	No Special Status
Ringed Seal (Alaska Stk)	*Phoca hispida*	No Special Status
Ross Seal	*Ommatophoca rossii*	No Special Status
Saimaa Seal	*Phoca hispida*	Endangered (ESA)
Southern Elephant Seal	*Mirounga leonina*	No Special Status
Spotted Seal	*Phoca largha*	No Special Status
Spotted Seal (Alaska Stk)	*Phoca largha*	No Special Status
Weddell Seal	*Leptonychotes weddellii*	No Special Status
West Indian Monk Seal (Caribbean Monk Seal)	*Monachus tropicalis*	Endangered (ESA)

PINNIPEDIA - FUR SEALS

Common Name	**Scientific Name**	**Status under ESA/MMPA**
Amsterdam Island Fur Seal	*Arctocephalus tropicalis*	No Special Status
Antarctic Fur Seal	*Arctocephalus gazella*	No Special Status
Cape Fur Seal	*Arctocephalus pusillus*	No Special Status
Galapagos Fur Seal	*Arctocephalus galapagoensis*	No Special Status
Guadalupe Fur Seal	*Arctocephalus townsendi*	Threatened (ESA)
Juan Fernandez Fur Seal	*Arctocephalus philippii*	No Special Status
Kerguelen Fur Seal	*Arctocephalus gazella*	No Special Status
New Zealand Fur Seal	*Arctocephalus forsteri*	No Special Status
Northern Fur Seal	*Callorhinus ursinus*	Depleted (MMPA)
Northern Fur Seal (Eastern Pacific Stock)	*Callorhinus ursinus*	Depleted (MMPA)
South African Fur Seal	*Arctocephalus pusillus*	No Special Status
South American Fur Seal	*Arctocephalus australis*	No Special Status
Subantarctic Fur Seal	*Arctocephalus tropicalis*	No Special Status
West Australian Fur Seal	*Arctocephalus forsteri*	No Special Status

SIRENIANS (MANATEES, DUGONGS)

Common Name	**Scientific Name**	**Status under ESA/MMPA**
Amazonian Manatee	*Trichechus inunguis*	Endangered (ESA)
Dugong	*Dugong dugon*	Endangered (ESA)

Steller's Sea Cow	*Hydrodamalis gigas*	Extinct
West African Manatee	*Trichechus senegalensis*	Threatened (ESA)
West Indian Manatee	*Trichechus manatus*	Endangered (ESA)

C.3 SEA TURTLE LIST

REPTILIA – TESTUDINES - SEA TURTLES

Common Name	Scientific Name	Status under ESA/MMPA
Flatback Sea Turtle	*Chelonia depressa*	
Green Sea Turtle (Florida Breeding Population)	*Chelonia mydas*	Endangered (ESA)
Green Sea Turtle (All Other Populations)	*Chelonia mydas*	Threatened (ESA)
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered (ESA)
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	Endangered (ESA)
Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered (ESA)
Loggerhead Sea Turtle	*Caretta caretta*	Threatened (ESA)
Olive Ridley Sea Turtle (Mexican Breeding population)	*Lepidochelys olivacea*	Endangered (ESA)
Olive Ridley Sea Turtle (All Other Populations)	*Lepidochelys olivacea*	Threatened (ESA)

APPENDIX D.
CRITERIA FOR INJURY AND HARASSMENT OF MARINE ANIMALS

This appendix is organized according to the following outline:

- D.1 Marine Mammals
    - D.1.1 Impulsive Noise
    - D.1.2 Non-Impulsive Noise
- D.2 Sea Turtles
- D.3 Other Marine Animals

While it is logical that a criterion for injury or harassment should not depend on the noise source or properties, the practical matter is that different criteria have been used for impulsive sources and non-impulsive sources. One reason is that impulsive noise can, is some cases, cause non-auditory physical injuries, and the criteria reflect the types of injuries observed.

D.1 MARINE MAMMALS

As noted above, the term "harassment" has no statutory definition under the ESA and only a broad definition under the MMPA. Recall that the 1994 amendment to the MMPA prohibits:

> "any act of pursuit, torment, or annoyance which:
>
> Level A – has the potential to injure a marine mammal or marine mammal stock in the wild; or
>
> Level B – has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

D.1.1 Impulsive Noise

D.1.1.1 Overview for Impulsive Noise

Most environmental assessments for activities at sea involving underwater impulsive noise categorize risk to marine mammals in terms of (a) mortal injury, (b) non-mortal injury, and (c) Level B harassment. For one recent action, NMFS has distinguished between serious and non-serious injury in terms of eventual likelihood of mortality. Until 1985 or later, harassment was usually interpreted as a physical sensation felt by the animal. Hence, most assessments emphasized risks of the first two types, even though "safe" ranges are usually driven by Level B harassment criteria.

For explosives, criteria used in past Navy compliance documents include those of Table D.1-.1.

Table D.1-1 Examples of Criteria for Injury and Harassment of Marine Mammals

Injury and Level A Harassment	Example of Use
Lethality from high peak pressure	*SEAWOLF* Shock Test FEIS (1998), Florida Straits LOA (1994)
Lethality due to cavitation	*SEAWOLF* Shock Test FEIS (1998), Florida Straits LOA (1994)
Extensive lung hemorrhage (50% mortality) for a calf dolphin of 12.2 kg.	*SEAWOLF* Shock Test FEIS (1998), Florida Straits LOA (1994)
Onset of extensive lung hemorrhage (1% mortality) for a calf dolphin of 12.2 kg.	Criterion for lethality in *SEAWOLF* Shock Test FEIS (1998)
Onset of slight lung hemorrhage for a calf dolphin of 12.2 kg.	*SEAWOLF* Shock Test FEIS (1998), Florida Straits LOA (1994)
50% tympanic membrane rupture, for an animal at bottom (152 m)	Criterion for injury in *SEAWOLF* Shock Test FEIS (1998), Florida Straits LOA (1994)
10% tympanic membrane rupture, for an animal at bottom (152 m)	Florida Straits LOA (1994)
Permanent Threshold Shift (PTS)	
Temporary Threshold Shift (TTS)	

Level B Harassment	Example of Use
Temporary Threshold Shift (TTS)	*SEAWOLF* Shock Test FEIS (1998)
Possible Behavioral Reaction – Significant Change of Migration Routes	
Possible Behavioral Reaction – Avoidance of Area Near Sources	
Brief physical discomfort	*SEAWOLF* Shock Test FEIS (1998)
Tactile Perception	*SEAWOLF* Shock Test FEIS (1998) and Florida Straits LOA (1994)
Possible Significant Behavioral Reaction	SSQ-110 EA (1995), ACT II EA (1993), DISTANT THUNDER ER (1998)

The selection of specific criteria for lethality, injury, and harassment is at the discretion of the developer of the compliance document. There has been no formal guidance from NMFS or within DOD. NMFS has endorsed one set of criteria for the SEAWOLF Shock Trial FEIS (1998). In the table, the specification of the lethality criteria for calf dolphins in terms of 1% mortality may not need to be so conservative. On the other hand, eardrum rupture at the 50% level as criterion for injury may be a level difficult to justify.

Harassment of protected marine animals includes significant disruption of behavioral patterns, including feeding and migration. The effects of noise include permanent threshold shifts (PTS), temporary threshold shifts (TTS), masking of predator noises, masking of communications, interference with searching for food, and, in some instances, annoyance. Various thresholds for the amount of noise it takes to result in harassment have been hypothesized.

Noises that degrade hearing sensitivity may cause serious problems for marine animals that depend significantly on their hearing. Certain marine animals are known to depend on their

hearing for everything from feeding and mating to protection from prey and communicating. Among marine mammals, essentially all cetaceans are in this category, as are sirenians, and most pinnipeds.

Criteria for harassment, beyond what might be deduced from the MMPA definition, are at issue and the subject of continued study. This was the main topic of a three-day workshop conducted by NMFS in September 1998. No results have been released to date, and the panel discussions highlighted the need for further research. The use of TTS as criterion for harassment is a much-discussed topic and the following paragraph provides some background.

D.1.1.2. TTS as a Criterion for Harassment (Level B) for Marine Mammals - Historical Information

Compliance with the Marine Mammal Protection Act (MMPA) is the issue of concern (although the Endangered Species Act may overlap for certain species). The wording of the MMPA is not precise, so that the legal definition of 'harassment' is subject to argument. One point that is very clear in the MMPA is that causing significant physical injury ('Level A' harassment) to a marine mammal is prohibited. "Level B' harassment is a behavioral impact, for which the regulators (NOAA's National Marine Fisheries Service [NMFS] for most marine mammals), marine biologists, acousticians, environmentalists, and lawyers have widely varying opinions. The term 'biologically significant' has been used by both regulators and technical investigators to indicate the type of behavioral response that is to be considered symptomatic of harassment. This term is also imprecise, but suggests that a startle response or even some avoidance response may not be serious enough to be considered harassment (e.g., NMFS Final Rule for SEAWOLF, 1998). On the other hand, significant changes in migration routes or the avoidance of a feeding area are sometimes judged by regulators to be cases of harassment (usually viewed in the context of the welfare of the regional population). As discussed below at length, NMFS has also recognized temporary hearing loss as the sole Level B harassment criterion for a number of specific cases.

In order to comply with the laws and to maintain its tempo of at-sea activities, the Air Force needs a well-defined and defensible criterion for harassment, as well as the corresponding thresholds for sound levels. Otherwise, there follows the risk of litigation, excessive mitigation procedures, disruption of exercises, etc. DOD (esp. Navy) and the regulator (NMFS) have identified a criterion and set of thresholds that were mutually agreeable, and have been used as the basis for a number of recent compliance actions (e.g., SEAWOLF, DDG 81, ACOMMS, LWAD, etc.). That criterion for Level B harassment is temporary hearing loss (temporary threshold shift or 'TTS'). For projectors and sonars, the sound levels that cause TTS depend on animal species and condition, signal frequency, duration of the signal, waveform, number of exposures, and other factors. For the specific question of mid-range sonars and east-coast sites, the Navy has already performed extensive testing on exactly the type of animal most likely to be at risk of harassment. The resulting harassment thresholds (sound levels that cause harassment) are based on testing of multiple animals and probably represent the 'best science available' today.

TTS has been an important metric for human hearing, and has been studied for terrestrial animals as well, for many years.

For underwater sound and marine mammals, TTS was mentioned as an example of marine mammal harassment in NMFS (1995). The topic is discussed at length in Richardson et al (1995) and Ketten (1995). Nonetheless, there were no measurements of TTS in marine mammals through 1996.

TTS was not used as a criterion for harassment in the first drafts of the SEAWOLF EIS (e.g., the DEIS, 1996), nor was it used as criterion in the DISTANT THUNDER ER (1998), the DDG 53 LOA (1995), the SSQ-110 EA (1995), the ACT II EA (1994), or the Florida Straits LOA (1994).

For explosives, the first major Navy compliance document to use TTS as criterion for harassment was the SEAWOLF FEIS (1998). In that case, it is the sole criterion for Level B harassment.

D.1.1.3. TTS as a Criterion for Harassment (Level B) for Marine Mammals - *SEAWOLF* FEIS (1998)

In formal reviews of compliance documentation, NMFS often issues notices in the Federal Register covering responses to comments and issuing a "rule" which describes NMFS evaluation of the proposed action and specifies certain mitigation and reporting requirements. The December 1998 announcement is especially relevant to this Appendix, since it addresses issues of criteria and thresholds.

In one application of the NMFS notice, the issue of whether TTS constitutes Level A harassment (slight injury) or Level B harassment (the usual interpretation) is resolved as follows in the notice for the final rule for the *SEAWOLF* Shock Test FEIS:

> "Therefore, the information provided in the FEIS supports the Navy's selection of temporary threshold shift (TTS) as a harrasment criterion for shock testing the USS SEAWOLF. NMFS concurs. TTS is being used as a measure of quantifiable harassment, as TTS may also result in behavior reflecting an adverse reaction, and TTS meets the definition of both Level A and Level B harassment definitions found in the MMPA. On a cellular level, TTS could be considered a very slight ``injury" in the sense of damage to hair cells in the ear and because TTS is temporary hearing loss, it could lead to a temporary disruption of behavioral patterns as specified in the statutory definition of Level B harassment. " (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

The use of TTS as the sole indicator of Level B harassment has also been at issue, as indicated in the following passage from the same Federal Register notice:

> "The 160-dB criterion [reference to the DDG 53 LOA] is based on a behavioral response which may be of questionable biological significance in the context of a single acoustic pulse. In the case of a continuous source (e.g., industrial noise) or repeated transient sources (e.g., seismic pulses), avoidance by a marine mammal could result in changes to migration, feeding, or reproduction patterns that could affect the energetics of both

individuals and populations. However, in the context of a single, brief pulse from a detonation, a momentary startle response causing an animal to dive or momentarily change course or speed is not likely to affect either the individual or the population. Such a minor response is well within the range of normal behaviors that an animal might exhibit at any time in response to other animals or other environmental stimuli. As a result, NMFS does not normally consider these simple, singular, reflex actions (e.g., alert, startle, dive response to a stimulus) by marine mammals to be sufficient on their own to warrant an incidental harassment authorization. On the other hand, NMFS does not concur with statements made by the Navy in response to a different rulemaking that the term "harassment" in the MMPA should be limited to changes in behavioral patterns of a magnitude that reflect an adverse reaction on the part of the animals such as intense fear or pain or behavior that is likely to harm the animal or its offspring. By statutory definition, the *de minimus* level (for Level B harassment) should be less intrusive on the animal than suggested by the Navy." (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

Neither for *SEAWOLF*, nor other assessments using TTS as criterion, are the degree or extent of TTS specified as part of the criterion. Conditions stated for the *SEAWOLF* FEIS are that the energy threshold be applied to 1/3-octave bands and to different parts of the spectrum for mysticetes and odontocetes (the former limited to the band above 10 Hz and the latter to the band above 100 Hz). This is included in the NMFS Federal Register notice.

As will be mentioned in subsequent parts of this Appendix, the Ridgway et al. (1997) paper is the basis for the threshold for SEAWOLF and at least one other compliance document (the AUTEC ER, 1998). The Ridgway paper documents temporary shifts in the masked threshold on the order of 5 dB for bottlenose dolphins subjected to 1-second tones. In applying the Ridgway result, the subject compliance documents are thus implicitly adopting the criterion of the Ridgway tests: a small (5 dB) shift in the masked threshold, where the masking field has spectrum level on the order of 25 dB above the absolute hearing threshold.

Of additional interest is the fact that most compliance documents do not link the criterion for TTS to any specific portions of the spectrum of hearing of the animals (other than the *SEAWOLF* FEIS removal of bands below 10 and 100 Hz for baleen and toothed whales, respectively). In particular, hearing loss at a single frequency or a small band of frequencies (e.g., 10 to 100 Hz or 3000 to 3500 Hz) has the same significance as the loss of hearing across a wide band. Threshold shifts of 5 dB are considered significant.

As standards evolve and research continues, issues related to this topic will undoubtedly be addressed.

D.1.1.4. Explosive Sources: Thresholds for Injury of Marine Mammals - Eardrum Rupture

Eardrum (tympanic membrane) rupture has been used as an injury criterion in a number of compliance documents over the past five or more years. Thresholds have been calculated for all of these cases by CD-NSWC/UERD (Naval Surface Warfare Center, Carderock Division, Underwater Explosions Research Division).

For the SEAWOLF FEIS (1998), the same model is used, with the total energy version and a criterion of 50% eardrum rupture as the criterion for non-fatal injury. This is the criterion used to determine injury takes and to establish a 'safe' range ('safe' from injury other than TTS). The actual threshold used is an energy flux density value of 1.17 psi-in (about 205 dB re 1 μPa^2-s).

Criteria listed in past compliance documents have included 5% through 95 % rupture rates. In all cases, the thresholds have been estimated by CD-NSWC/UERD and are derived from the Lovelace data for dogs. Note that Lovelace [Yelverton et al. (1973)] provides a threshold in terms of positive impulse, while CD-NSWC/UERD use an energy model to fit the data. A sample of the estimated thresholds is given in the table below.

Note that the 50% rate replaced a 10% criterion in the *SEAWOLF* FEIS evolution on the basis of confidence in the estimate of impact rather than on the impact itself. The choice of the 50% rupture rate as criterion was thus based on statistical significance of deductions from the data, and not on a direct choice of rupture rate indicative of no physical injury (other than TTS). A 30% PTS incidence (associated with the 50% criterion) may not always be tolerable for a "no-injury" zone. The ratio of thresholds for 10% and 50% incidence is about 8, which is quite significant in the estimation of influence zones.

D.1.1.5 Eardrum Rupture Criteria for SEAWOLF FEIS (1998)

Two explanations were provided to the Navy for the adoption of a 50% eardrum rupture criterion over a 10% criterion for the Final EIS.

> During the review process for the SEAWOLF EIS, Dr. Darlene Ketten pointed out that the 10% eardrum rupture criterion was statistically meaningless and inappropriate as a metric. The 100% eardrum rupture criterion was described as moot, since the magnitude of the shockwave loading required for 100% eardrum rupture generally would be sufficient to severely injure or kill most animals (internal organ injuries).
>
> The 50% eardrum rupture is statistically significant and correlates to ~30% incidence of PTS (Dr. Ketten, during SEAWOLF EIS review). This is a good indicator with a blank in the Table for the metric! Based on Yelverton-Richmond data, the SEAWOLF EIS used an energy flux density of 1.17 in-lb/in^2 as the criterion for 50% eardrum rupture. For conservatism, the SEAWOLF EIS used the total calculated shockwave energy in the direct, surface and bottom reflected pressure waves and did not limit the energy to 0.1 msec duration or apply a time limit related to the integration time of the ear.

and:

> At the acoustic criteria workshop hosted by NMFS 9-11 September 1998, NMFS posed several questions regarding the SEAWOLF approach to a panel of experts that included Dr. Ketten, Tyack Richardson etc. and which was attended by several environmental advocacy groups. The panel was asked to consider the following specific questions and they gave the following specific answers;

The Panel was asked whether they agreed with a 50% eardrum rupture as a criterion for explosion effects on marine mammals or whether a mitigation level of 10% was better. Dr. Ketten explained that she instructed the Navy, while they were developing the SEAWOLF EIS, to lower the eardrum rupture standard because they could not validate the 10%. Enough data exists about eardrum rupture in marine mammals to indicate that first, at 50% threshold level approximately 1/3 of the animals will experience TTS (sic). And second, that beyond this 50% pressure zone the occurrence of PTS is highly individualistic and variable, thus accurately extrapolating to 10% is impossible.

A few panel members mentioned that they felt 50% might not be conservative enough. Ken Hollingshead of NMFS emphasized the fact that for the SEAWOLF EIS the Navy assumed a full take within the 50% limit even though data indicates only 1/3 take at 50%. In addition, Dr. Ridgway remarked that SEAWOLF upped the mitigation limit to three miles from the previous two and he feels comfortable with that limit. Given the available data SEAWOLF conservatively uses the best available data."

The choice of the 50% rupture rate as criterion was thus based on statistical significance of deductions from the data, and not on a direct choice of rupture rate indicative of no physical injury (other than TTS). A 30% PTS incidence may not always be tolerable for a "no-injury" zone. The ratio of thresholds for 10% and 50% incidence is about 8. The energy level difference is thus about 9 dB, which is quite significant in the estimation of influence zones. [The estimated 'safety range was 3792 m for an animal at the bottom under the 10% criterion, and 1853 m for an animal on the bottom for the 50% criterion. Sensitivity of the range to animal depth is attributed to sound propagation properties rather than depth dependence of the threshold.]

D.1.1.6 Injury of Marine Mammals by Explosives - Lovelace Foundation and Goertner Model

Underwater explosive tests on terrestrial mammals conducted in the early 1970s are the backbone of current estimates of physical injury to the lungs, intestines and eardrums of marine mammals. The principal experimental work is that done by Yelverton , Richmond, and others at the Lovelace Foundation in the 1970s (see references for Yelverton and Richmond). They exposed terrestrial animals to the sound field in water generated by small explosives. Models for injury to marine mammals (and other marine animals) have been developed on the basis of those data by the Lovelace scientists, as well as by Goertner (1984), BBN(1994), Ketten (1995) and others.

Criteria to which the thresholds correspond take such forms as: 50% mortality, onset of slight lung hemorrhage, onset of serious lung hemorrhage with 1% mortality, onset of intestinal injury, 50% eardrum rupture, etc. Thresholds are given in terms of peak pressure, positive impulse, and energy flux density (as are traditionally used for explosives) for each type and size of marine mammal. All of these threshold estimates were derived by extrapolation from experiments performed on terrestrial animals by the Lovelace Foundation.

The Goertner models for injury to marine animals have served as the basis for risk estimates for virtually all compliance documents dealing with underwater explosions since the models were

developed in the 1970s and 1980s. Except for the Goertner models or direct use of the Lovelace data and regression formulas, we know of no other quantitative models that have been used to account for lung or GI injuries to marine mammals and turtles, and no other models have been referenced in any compliance documents prepared by the Navy.

In the SEAWOLF Shock Trial FEIS (1998), the criterion for mortality corresponds to the 1% mortality condition listed in the Lovelace regression formulas.

Goertner (1982) also developed models and threshold estimates for GI injury. The damage is modeled as a function of bubble excitation, and the damage estimated from

$$P_{MAX}/P_o,$$

the ratio of peak (over)pressure to hydrostatic pressure. He uses the Lovelace data to estimate a condition of slight injury for the case that P_{MAX} is about 600 psi (253 dB re 1 μPa) and P_o is about atmospheric pressure. Animal depth is thus critical, and by 10 m the threshold for peak pressure would be 1200 psi (259 dB).

The decrease in range as depth increases beyond the point for maximum range (greatest impulse) is not a propagation effect. It is actually the result of the fact that the model uses a significantly different definition of positive impulse to account for the diminished impact as the animal's depth increases and lungs compress (or collapse).

An overview of the Goertner model for mammals, as applied to risk assessment, is taken directly from the Florida Straits LOA (1994):

> "Using data from the Yelverton, et al. (1973) report, Goertner (1982) developed a conservative computer model for the two primary injury mechanisms to mammals exposed to underwater explosion shockwaves. These mechanisms are: (1) lung hemorrhage, and (2) contusions fo the G.I. tract. For lung hemorrhage, Goertner's model considers lung volume as a function of animal weight and depth and considers shockwave duration and impulse tolerance as a function of animal weight and depth. Injury to the G.I. tract was indexed to the ratio of peak shockwave pressure to the hydrostatic pressure at the mammal location. Injury to the G.I. tract is considered independent of mammal size and weight. ...G.I. tract injury would generally be expected to occur at ranges less than those for the onset of slight lung injury."
>
> "... The reference values used in the Goertner model are the lowest impulse and body mass for which slight lung injury was reported by Richmond, et al. (1973) -- 22.8 psi-msec (155.4 Pa-sec) and 93 lb (42 kg).

The same document gives the Goertner estimates for extensive lung hemorrhage (50% mortality) and for the onset of extensive lung hemorrhage (1% mortality).

D.1.1.7. Impulsive Noise -Injury of Marine Mammals - Ketten (1995)

Ketten (1995) has been used as a source of information for criteria and thresholds for several compliance documents, including the recent SEAWOLF Shock Test FEIS (1998). Estimates for various effects on marine mammals for explosive energy are given on pages 402 to 404 of Ketten (1995). These estimates are based on the Lovelace data, data for humans in water, and on data for animals and humans in air. The estimates are given in the table below (with modifications for units and conversions).

Table D.1-2 Peak Pressure versus Marine Mammal Injury and TTS (Ketten, 1995)

Units		Lethal	Mixed Lethal/ PTS	PTS >50%	Mixed PTS/TTS	TTS: Moderate to None
psi		1100	350-1100	100-350	15-100	5-15
dB re 1 μPa		258	248-258	237-248	220-237	211-220

The metric is peak pressure and the estimates are intended to apply to sound generated by explosives.

To avoid physical injury (except TTS) for marine mammals, the peak pressure level, according to the table, should be below 100 psi (237 dB re 1 μPa), where Ketten estimates vulnerability to PTS. No indication is given on the relative vulnerability of one or another species of marine mammal or of mass or hearing sensitivities.

D.1.2 Non-Impulsive Noise

Richardson and Wursig (**1997**) identify four effects of noise on whales: (1) Disturbance reactions, from subtle changes to long-term displacement, (2) Masking, (3) Hearing threshold shifts, and (4) Physiological stress. Any of these could be a criterion for harassment under the MMPA.

As a practical matter, criteria for harassment under MMPA used over the last several years were inspired by three technical investigations: TTS measurements on small odontocetes and on pinnipeds (by Ridgway, etc), the behavioral responses of the animals during the TTS tests, and baleen whale reactions to low-frequency sound observed in the LFA-SRP and MMRP (see NRC, 2000, for summaries).

TTS, as discussed in the section on impulsive noise, is an important criterion - but it has been used only occasionally in formal compliance documents (e.g., AUTEC ER) for non-impulsive noise. Questions about the interpretation of the masked TTS results have led planners to use the behavioral responses as criteria.

As for low-frequency noise, the ATOC and LFA research programs have seen a range of interpretations. Some thresholds are based on criteria related to subtle changes in whale vocalizations or migration paths.

NRC (1996) Report on Low-Frequency Sound

In revisiting the 1994 NRC study, the expert panel made provided information and opinions directly relevant to the criterion and threshold question for mammals:.

> "Specifically, the Committee believes that regulations must focus on activities that significantly disrupt behavior critical to marine mammal survival and reproduction." (Executive Summary, page 2)

On page 18,

> "The Committee supports this effort to distinguish between injury and disruption of behavior. For acoustic harassment, measurement of TTS may provide a conservative estimate of safe exposure levels with regard to injury (Level A above). Thus, sounds with intensities lower than those expected to produce TTS should be considered noninjurious."
>
> "The Committee believes that it does not make sense to regulate minor changes in behavior with no adverse impact; rather, regulations must focus on significant disruption of behaviors critical to survival and reproduction, which is the clear intent of the definition of harassment in the MMPA."
>
> "The Committee believes that NMFS should regulate all effects of sound on marine mammals on the same basis: their biological significance."

D.2 SEA TURTLES

For explosives, the O'Keeffe and Young (1984) report recommends a safe range for sea turtles for planning purposes depending only on charge mass. The formula is based on observations following a 1200-pound explosion off Panama City in 1981. In that case, a 400 pound turtle within 500-700 feet was killed, while 200-300 pound turtles were slightly injured at 1200 feet and not at all at 2000 feet. The O'Keefe and Young report then extrapolates the safe range according to the above formula, "based on cube root scaling."
Thus, there is no specific criterion for injury other than: mortality, slight injury, and no injury. There are no other conditions associated with the formula. Estimated safe range does not depend on turtle size or weight or depth, nor on any parameters affecting propagation of the sound waves (e.g., water depth, bottom properties, sound speed field, charge depth, etc.).

The O'Keeffe and Young range of 200 feet times cube-root of charge weight thus corresponds to a peak pressure for injury to sea turtles of about 50 psi (for ideal environment, etc). The corresponding peak pressures for the experimental data listed would then be estimated as: 169 psi (242 dB) for mortality, 77 psi (235 dB) for slight injury, and 43 psi (230 dB) for no apparent injury.

D.2.1 Harassment

The principal criterion for harassment of sea turtles by impulsive sources is TTS, as applied in the SEAWOLF FEIS (1998) and approved by NMFS. The threshold for sea turtles is the same as

that used for marine mammals.

D.2.2 Compliance Documents-SEAWOLF Shock Test FEIS (1998)

The SEAWOLF FEIS (1998) compared the Young (1991) formula for injury of Sea Turtles against the injury 'safety' range for mammals, based on a criterion of 50% eardrum rupture and a one mile 'buffer' zone. The Young formula for the 10,000 pound explosive yields about 12,000 feet, nearly identical with the injury safety zone for mammals of 2 nmi. Take estimates were based on the 2 nmi range (without any additional buffer zone beyond the Young (1991) range). No adjustment to the Young formula was made to account for the shallow, range-dependent environment (given the Young formula cube-root law, the corresponding similitude equations for shock waves follow a '23 log R' rule for propagation loss). No adjustments were made for turtle sizes.

For harassment of sea turtles, the SEAWOLF FEIS (1998) used the same criterion (TTS) and the same thresholds as for marine mammals. In particular, data on turtle hearing was used to justify the elimination of explosive energy below 100 Hz, and thus the use of the harassment zone determined for odontocetes.

In the FEIS, behavioral responses for turtles beyond the TTS range (about 8.5 nmi) were estimated as not likely to be significant because of the fact that time between shots is long (order weeks) and duration of the signal short (listed as <50 ms). The latter argument may be unreliable since it is not unusual for the duration of significant arrivals from a shot signal in shallow water to significantly exceed 50 ms at a few miles.

D.3 OTHER MARINE ANIMALS

The principal sources cited in compliance documents for effects of explosive energy on fish, birds and invertebrates are Yelverton et al. (1973, 1981) and Young et al. (1992b).

Mortality and injury tables for impulsive sound have been established by experiment, and are given in terms of two metrics: peak pressure and positive impulse (Yelverton et al, 1973 and 1981). These thresholds were derived from tests using explosives and terrestrial animals and fish in water. Most risk assessments limit the gradation of injury/harassment to: "safe" and "50% mortality," following Yelverton et al.

APPENDIX E.
BACKGROUND ON THRESHOLDS FOR IMPACT OF UNDERWATER, IMPULSIVE NOISE ON MARINE MAMMALS

This appendix is organized according to the following outline:

- E.1 Thresholds for Mortality and Injury
  - E.1.1 Introduction
  - E.1.2 Lovelace Foundation
  - E.1.3 Goertner Models
  - E.1.4 Ketten (1995)
  - E.1.5 Eardrum Rupture
  - E.1.6 Eglin AFB Assessment (1998)
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- E.2 Thresholds for Non-Injurious Harassment
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  - E.2.3 TTS - SEAWOLF FEIS (1998)
  - E.2.4 Ketten (1995)
  - E.2.5 Baleen Whale Avoidance and Harassment for Air Guns (Malme, Richardson, and others)
  - E.2.6 Thresholds Used in the Eglin AFB Assessment (1998)
  - E.2.7 Hearing Bands of Marine Mammals
  - E.2.8 Ridgway TTS Study - Applied to Explosive Sources
  - E.2.9 MMS/ITM (1998) Workshop: HESS Committee Findings for Thresholds

E.1 THRESHOLDS FOR MORTALITY AND INJURY

E.1.1 Introduction

As discussed in Section 4, there is a long history connected with the risk assessment for injury to marine mammals from impulsive sounds. This is especially true for explosive-generated noise, but the same thresholds are usually applied for other impulsive noises (airguns, sonic booms, sparkers, etc.).

Most environmental assessments for activities at sea involving underwater explosives categorize risk to marine mammals in terms of (a) mortal injury, (b) non-mortal injury, and (c) Level B harassment. For one recent action, NMFS has distinguished between serious and non-serious injury in terms of eventual likelihood of mortality. Until 1985 or later, harassment was usually interpreted as a physical sensation felt by the animal. Hence, most assessments emphasized risks of the first two types, even though "safe" ranges are usually driven by Level B harassment criteria.

The tables of Section 4 show the most often used thresholds for various types of injuries. Discussions on the sources of these thresholds, and the interpretation of the metrics (e.g., modified positive impulse) are given in this subsection.

E.1.2 Lovelace Foundation

Underwater explosive tests on terrestrial mammals conducted in the early 1970s are the backbone of current estimates of physical injury to the lungs, intestines and eardrums of marine mammals. The principal experimental work is that done by Yelverton , Richmond, and others at the Lovelace Foundation in the 1970s (see references for Yelverton and Richmond). They exposed terrestrial animals to the sound field in water generated by small explosives. Models for injury to marine mammals (and other marine animals) have been developed on the basis of those data by the Lovelace scientists, as well as by Goertner (1984), BBN(1994), Ketten (1995) and others.

Thresholds for physical injury (other than auditory threshold shifts) to marine mammals (and other marine animals) by explosives remain about the same today as when they were first established. While these thresholds are subject to challenge, they almost always lead to safe ranges smaller than those for harassment and hence are useful as a lower bound or for defining a truly "hazardous" zone in which animals risk serious bodily harm. They are the basis for estimating 'takes' which are mortal or injurious. There have been no serious technical challenges to the thresholds in use today, and the approach is apparently viewed by regulators as adequate. Excluded from this broad statement are auditory threshold shifts (such as TTS and PTS).

Criteria to which the thresholds correspond take such forms as: 50% mortality, onset of slight lung hemorrhage, onset of serious lung hemorrhage with 1% mortality, onset of intestinal injury, 50% eardrum rupture, etc. Thresholds are given in terms of peak pressure, positive impulse, and energy flux density (as are traditionally used for explosives) for each type and size of marine mammal. All of these threshold estimates were derived by extrapolation from experiments performed on terrestrial animals by the Lovelace Foundation.

E.1.2.1 Lovelace Experiments

Primarily under Defense Nuclear Agency (DNA) funding, but with Navy participation, an artificial pond (called Lake Christian) was constructed in 1969 at Kirtland Air Force Base, Albuquerque NM. Beginning in 1970, the Lovelace Foundation conducted experiments for the purpose of learning the effects of underwater explosions on humans and animals (see Yelverton et al and Richmond et al references).

The Lovelace experiments consisted of tests on selected species of fish, birds (mallard ducks), and mammals (rats, muskrats, rabbits, dogs, monkeys and sheep). As an examples of scope, one series of 55 tests utilized 101 sheep, 37 dogs, and 6 monkeys. In the case of mammals, animals were lowered horizontally or vertically (head up) into the water and subjected to blasts from small charges (one pound to eight pounds TNT equivalent) at short ranges. In most cases the sheep heads were above the water. When not, air supplies and masks were used. All animals were autopsied within two hours of the test. The principal injuries investigated for the sheep and monkeys were to the lungs and intestines.

The only test for eardrum damage was that for the dogs, which were "sacrificed" prior to the test to ensure their heads were properly oriented and stable. Laboratory analyses focused on ear-drum rupture. Hearing tests were conducted for none of the animals.

The tests have provided the primary data set from which all (non-auditory) injury estimates for marine mammals are made. The Lovelace results have been used by many investigators (e.g., Ketten, 1995, Richardson et al, 1995). Most often quoted are the Goertner (1982) estimates, which use the Lovelace data for absolute thresholds. These estimates are the basis for the Young (1991) and O'Keeffe and Young (1984) reports, as well as the thresholds for injury used in most environmental assessments, including SEAWOLF FEIS (1998), Straits of Florida LOA (1994), and DDG 53 LOA (1995).

As cited in most compliance documents dealing with explosives (e.g., ACT II EA, 1995; SEAWOLF FEIS, 1998), Yelverton (1981) fits the mammal test results to regression equations:

$$\text{Positive Impulse} = 20.5\ M^{0.386}\ \text{psi-ms} \ \text{- for 50\% mortality}$$

$$\text{Positive Impulse} = 13.3\ M^{0.386}\ \text{psi-ms} \ \text{- for 1\% mortality}$$

$$\text{Positive Impulse} = 7.2\ M^{0.386}\ \text{psi-ms} \ \text{- for ``no injuries''}$$

where M is animal mass in kg. Notice that the threshold increases at a rate faster than $M^{1/3}$, and the ratio of the impulse for 50% mortality to that for no injuries is about 3.

The regression formulas are quoted in most compliance documents, but not actually used to determine thresholds for injury. Instead, somewhat different curve-fits to the Lovelace data have been developed and other models used for specific types of injuries. Those models used in recent compliance documents are reviewed in the next several subsections.

E.1.3 Goertner Models

The Goertner models for injury to marine animals have served as the basis for risk estimates for virtually all compliance documents dealing with underwater explosions since the models were developed in the 1970s and 1980s. Except for the Goertner models or direct use of the Lovelace data and regression formulas given above, we know of no other quantitative models that have been used to account for lung or GI injuries to marine mammals and turtles, and no other models have been referenced in any compliance documents prepared by the Navy.

An overview of the Goertner model for mammals, as applied to risk assessment, is taken directly from the Florida Straits LOA (1994):

> "Using data from the Yelverton, et al. (1973) report, Goertner (1982) developed a conservative computer model for the two primary injury mechanisms to mammals exposed to underwater explosion shockwaves. These mechanisms are: (1) lung hemorrhage, and (2) contusions fo the G.I. tract. For lung hemorrhage, Goertner's model considers lung volume as a function of animal weight and depth and considers shockwave duration and impulse tolerance as a function of animal weight and depth. Injury to the G.I. tract was indexed to the ratio of peak shockwave pressure to the

hydrostatic pressure at the mammal location. Injury to the G.I. tract is considered independent of mammal size and weight. ...G.I. tract injury would generally be expected to occur at ranges less than those for the onset of slight lung injury."

"... The reference values used in the Goertner model are the lowest impulse and body mass for which slight lung injury was reported by Richmond, et al. (1973) -- 22.8 psi-msec (155.4 Pa-sec) and 93 lb (42 kg). After correcting for the atmospheric and hydrostatic pressure for the data, the baseline impulse for predicting the onset of slight lung hemorrhage is:

$$I = 19.0\,(M/42)^{1/3}\ \text{psi-msec}, \quad [= 5.5\,M^{1/3}\ \text{psi-msec}]$$

... where M is the body mass (in kg) of the subject animal."

"...The calculated range for onset of slight lung hemorrhage for a 220 lb (100 kg) mammal from a 10,000-lb (4536-kg) charge...yields a maximum slant range of 6069 ft (1850 m) for the onset of slight lung hemorrhage."

Note that the threshold for injury for the Florida Straits LOA is a range, determined as twice the range for which a 100-kg mammal would experience the onset of slight lung hemorrhage. From the paragraph above, confirm that this calculated range is 3700 m. Also note that the impulse level at which the 100 kg animal is expected to suffer slight lung hemorrhage is, according to the formula above, about 25.4 psi-ms.

The same document gives the Goertner estimates for extensive lung hemorrhage (50% mortality) and for the onset of extensive lung hemorrhage (1% mortality):

$$I_{50\%} = 83.4\,(M/43)^{1/3}\ \text{psi-ms} \quad [= 23.8\,M^{1/3}\ \text{psi-msec}]$$

$$I_{1\%} = 42.0\,(M/34)^{1/3}\ \text{psi-ms} \quad [= 13.0\,M^{1/3}\ \text{psi-msec}],$$

where M is mammal mass in kg.

Compare these two formulas with the original Lovelace formulas above ($I_{50\%} = 20.5\,M^{0.386}$ psi-ms and $I_{1\%} = 13.3\,M^{0.386}$ psi-ms) to confirm that the two regressions for the Lovelace data are nearly the same.

Except for slight differences in coefficients (e.g., 42.9 instead of 42.0), these same formulas are used in the SEAWOLF FEIS (1998), and the criterion for mortality corresponds to the 1% mortality condition listed here. The threshold for mortality as used in the FEIS is:

$$I_{1\%} = 42.9\,(M/34)^{1/3}\ \text{psi-ms} \quad [= 13.2\,M^{1/3}\ \text{psi-msec}]$$

The actual threshold for 1% mortality quoted in Tables 4-4 and D-9 of the SEAWOLF FEIS (1998) is 55.1 psi-ms for a 12.2 kg calf dolphin. It is not calculated from this formula. 55.5 psi-ms is the threshold used to estimate the 'lethal' range (1.12 km) and the number of lethal 'takes' for the FEIS.

Goertner (1982) also developed models and threshold estimates for GI injury. The damage is modeled as a function of bubble excitation, and the damage estimated from

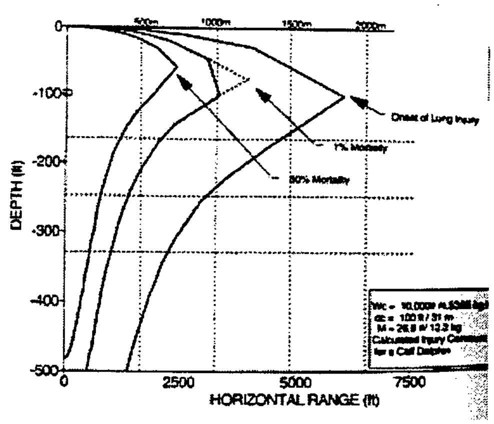
$$P_{MAX}/P_o,$$

the ratio of peak (over)pressure to hydrostatic pressure. He uses the Lovelace data to estimate a condition of slight injury for the case that P_{MAX} is about 600 psi (253 dB re 1 μPa) and P_o is about atmospheric pressure. Animal depth is thus critical, and by 10 m the threshold for peak pressure would be 1200 psi (259 dB).

Associated with the Goertner estimates in several compliance documents has bee a "peak pressure" level for lethality based on seal-bomb observations by Myrick et al. (1990). Estimated lethal peak pressures for explosives range from 1400 psi (260 dB) to 1700 psi (262 dB), as used, for example, in the Florida Straits LOA (1994) and the *SEAWOLF* FEIS (1998).

Depth Dependence in the Application of the Goertner models.

The plot below is typical of those calculated with the Goertner lung injury model, and very similar plots can be found in Goertner(1982), O'Keefe and Young (1984), Young (1991), Richardson et al. (1995), the SEAWOLF FEIS (1998), the Florida Straits LOA (1994), etc.



Notice that the depth dependence of the range-depth curve for constant impulse can be quite significant. It is important to note in interpreting and using such results that the only depth dependence exhibited that is caused by sound propagation effects is the so-called 'cutoff' of the positive phase of the impulse by the surface-reflected path. Cutoff (or surface decoupling or ...) is important when the direct and surface-reflected propagation paths have nearly the same travel times. This is the case when the source or animal is near the surface, and is reflected in the figure by the dramatic decrease in range (decrease in positive impulse) as the source (or animal) approaches the surface. It is a direct result of the fact that the ocean surface is approximately a pressure-release boundary at which the pressure must be zero. Except for large explosives, most of the applications of the Goertner model are for short ranges in deep water, and do not include any sound propagation effects (other than cutoff by the surface-reflected path).

The decrease in range as depth increases beyond the point for maximum range (greatest impulse) is not a propagation effect. It is actually the result of the fact that the model uses a significantly different definition of positive impulse to account for the diminished impact as the animal's depth increases and lungs compress (or collapse).

Specifically, the Goertner model uses a 'partial' impulse, calculated as

$$\int_0^{T_{MIN}} p(t)\,dt \;,$$

where p(t) is the pressure wave from the explosive, at a fixed location, as a function of time. The time scale is set so that $p(t) = 0$ for $t < 0$. The upper limit of the integral is defined as:

$$T_{MIN} = \min\{T_{pos}, T_{osc}\},$$

where T_{pos} is the time to cutoff, and T_{osc} is a function of the air-bubble (lung) oscillation period. The integral with upper limit T_{pos} is the positive impulse, by definition. When $T_{osc} < T_{pos}$, then the 'partial impulse' is smaller than the positive impulse. When compared to a threshold for injury, it will thus predict less impact than would the true positive impulse.

T_{osc} is estimated in Goertner (1982) as proportional to $M^{1/3}/(1 + Z_a/33)^{5/6}$, where M is animal mass and Z_a is animal depth. It is thus a monotonically decreasing function of depth. T_{pos} is usually calculated in the isospeed approximation as proportional to

$$(R^2 + (Z_a + Z_s)^2)^{1/2} - (R^2 + (Z_a - Z_s)^2)^{1/2}$$

where R is range and Z_s is charge depth. Thus T_{pos} is 0 (and impulse is 0) when either charge or animal is at the surface. T_{pos} increases (as does impulse) with animal depth or source depth.

For a fixed animal mass, charge depth and size, the maximum range at which a specific threshold is attained corresponds in most practical cases to an animal depth for which $T_{osc} = T_{pos}$. This is the location of the range peak in the range-depth curve shown. It is easily calculated.

Note that without the Goertner model and modification to the positive impulse, "safe" ranges based on impulse would be many times greater.

Questions about the meaning of positive impulse outside of the ideal environment, and approaches for estimating it are difficult, and have not been addressed in the literature or in previous risk assessments.

Thresholds for Goertner Model

The thresholds (called 'risk functions' in the 1982 report) used with the modified impulse are also depth dependent. It is not clear why it falls off so rapidly [like $(1 + z_a/33)^{-1/2}$] in all of the calculations of depth dependence (as in the figure above).

In the early reports on fish with swimbladders, the falloff seems rapid, even though the risk function is approximated in such a way that it does not depend on depth.

The 1982 report on mammals shows an injury function that decreases like $(1 + z_a/33)^{-1/6}$ a rate so slow that calculations of the full modified impulse against this threshold fall off much more slowly than the plots in the text. Nowhere in the Goertner documentation is there any indication of why this is so, except that the metric

$$I / [A(z) * \mathrm{sqrt}(\rho * p(z)]$$

is given at the start (with ρ the density).

This would explain it all if it were not for the fact that the radius of the bubble (lung) decreases with depth like $p(z)^{1/3}$. In fact the formula given is

$$A(z) = A(0)\ (p(0)/p(z))^{1/3}$$

where p(0) is atmospheric pressure and A(0) is the radius at atmospheric pressure, p (0)..

yielding a damage parameter function of form:

$$I / (\rho^{1/2}\ p(z)^{1/2}\ p(0)^{1/3}\ p(z)^{-1/3}).$$

The final "damage parameter" for scaling lung injuries given in the 1982 Goertner report is

$$I/(M^{1/3}\ p(0)^{1/3}\ p(z)^{1/6}).$$

However, plots in provided with SEAWOLF FEIS (1998) and other risk assessments can be matched exactly when a different depth dependence is used. The following steps lead to the match:

A) The similitude equations of Goertner (including the functional form for the pressure wave p(t)) are used to calculate the modified positive impulse:

Integral from 0 to T_{mod} of p(t) dt.

B) T_{mod} is calculated as the min of (T_{cut} , $0.2T_{osc}$), where T_{cut} is the time to cutoff, and T_{osc} has value $5.6\ M^{1/3}\ (1+z/33)^{-5/6}$

C) For a given threshold value at the z = 0 (from Yelverton), the depth dependent threshold is TH(0) $(1+z/33)^{1/2}$

D) For given values of M, w, z_s, the equation:

$$TH(z) = \text{Modified positive impulse at depth z}$$

is satisfied for each z by a value of R (range).

E) R(z) is plotted for selected TH(0), M, w, and z_s.

E.1.4 Ketten (1995)

Ketten (1995) has been used as a source of information for criteria and thresholds for several compliance documents, including the recent SEAWOLF Shock Test FEIS (1998). Estimates for various effects on marine mammals for explosive energy are given on pages 402 to 404 of Ketten (1995). These estimates are based on the Lovelace data, data for humans in water, and on data for animals and humans in air. The estimates are given in the table below (with modifications for units and conversions).

Table E.1-2 Peak Pressure versus Marine Mammal Injury and TTS (Ketten, 1995)

Units	Lethal	Mixed Lethal/ PTS	PTS >50%	Mixed PTS/TTS	TTS: Moderate to None
Psi	1100	350-1100	100-350	15-100	5-15
dB re 1 μPa	258	248-258	237-248	220-237	211-220

The metric is peak pressure and the estimates are intended to apply to sound generated by explosives. The TTS effects listed in the table are discussed in the next section (D.2).

To avoid physical injury (except TTS) for marine mammals, the peak pressure level, according to the table, should be below 100 psi (237 dB re 1 μPa), where Ketten estimates vulnerability to PTS. No indication is given on the relative vulnerability of one or another species of marine mammal.

It is not possible to compare peak pressure values with the positive impulse and energy values given in previous subsections unless information on the waveform is known. For explosives, the waveform depends on the size, shape, and depth of the shot, as well as the propagation of the waves. The "similarity" or "similitude" equations can sometimes resolve this issue, but apply to the case of an idealized waveform in an idealized iso-speed half-space for non-linear shockwave propagation. Various versions of these formulas are discussed in Cole (1948), Weston (1960), Christian and Gaspin (1974), Urick (1967), Goertner (1982), and many other references. One important issue associated with the similarity equations is that they are not generally valid for linear acoustic waves, nor are they accurate for cases other than those of a dominant, straight-line direct path (and an ideal surface-reflected path, in some versions). As a result, range estimates based on these formulas are

suspect if the conditions are much different from the ideal. This is the motivation for expressing thresholds in terms of sound metrics at range, rather than in terms of ranges from the source.

E.1.5 Eardrum Rupture

Eardrum (tympanic membrane) rupture has been used as an injury criterion in a number of compliance documents over the past five or more years. Thresholds have been calculated for all of these cases by CD-NSWC/UERD (Naval Surface Warfare Center, Carderock Division, Underwater Explosions Research Division).

The Florida Straits LOA (1994) describes a model based on the Lovelace data and stated as:

$$\ln R_{\%} = 3.734 + 0.719 \ln E$$

where $R_{\%}$ is the incremental rupture percentage and E is the total shockwave energy (in psi-in).

To accommodate larger and/or deeper charges, the equation was modified:

$$\ln R_{\%} = 3.778 + 0.767 \ln E_i$$

where $R_{\%}$ is the incremental rupture percentage and E_i is the incremental shockwave energy (in psi-in). 'Incremental shockwave energy' is the energy in a 0.1 msec time interval.

The threshold, as presented, is independent of mammal size, species, depth, and independent of charge weight and depth. The only dependencies on depth are those associated with propagation of the pulse. No depth dependence in the range contours is indicated in the Florida Straits LOA (1994).

For the SEAWOLF FEIS (1998), the same model was used, but with total energy instead of incremental energy. The criterion 50% eardrum rupture was the criterion for non-fatal injury. This is the criterion used to determine injury takes and to establish a 'safe' range ('safe' from injury other than TTS). The actual threshold used is an energy flux density value of 1.17 psi-in (about 205 dB re 1 μPa^2-s).

Table E.1-3. Examples of Thresholds for Eardrum Rupture

Rupture Percentage	Threshold Metric	Threshold	Reference
10%	Energy Flux Density	0.14 psi-in (25 J/m^2) (196 dB re 1 μPa^2-s)	*SEAWOLF* DEIS (1996)
50%	Energy Flux Density	1.17 psi-in (205 J/m^2) (205 dB re 1 μPa^2-s)	*SEAWOLF* FEIS (1998)
"high incidence"	Positive Impulse	40 psi-ms (276 Pa-s)	Yelverton et al (1973)
50%	Positive Impulse	20 psi-ms (138 Pa-s)	Yelverton et al (1973)
0%	Positive Impulse	10 psi-ms (69 Pa-s)	Yelverton et al (1973)

Criteria listed in past compliance documents have included 5% through 95 % rupture rates. In all cases, the thresholds have been estimated by CD-NSWC/UERD and are derived from the Lovelace data for dogs. Note that Lovelace [Yelverton et al. (1973)] provides a threshold in terms of positive impulse, while CD-NSWC/UERD use an energy model to fit the data. A sample of the estimated thresholds is given in the table above.

Note that the 50% rate replaced a 10% criterion in the *SEAWOLF* FEIS evolution on the basis of confidence in the estimate of impact rather than on the impact itself. The choice of the 50% rupture rate as criterion was thus based on statistical significance of deductions from the data, and not on a direct choice of rupture rate indicative of no physical injury (other than TTS). A 30% PTS incidence (associated with the 50% criterion) may not always be tolerable for a "no-injury" zone. The ratio of thresholds for 10% and 50% incidence is about 8, which is quite significant in the estimation of influence zones.

E.1.5.1: Eardrum Rupture Criteria for SEAWOLF FEIS (1998)

Two explanations were provided for the adoption of a 50% eardrum rupture criterion over a 10% criterion (used in the DEIS) for the Final EIS:

> "During the review process for the SEAWOLF EIS, Ketten pointed out that the 10% eardrum rupture criterion was statistically meaningless and inappropriate as a metric. The 100% eardrum rupture criterion was described as moot, since the magnitude of the shockwave loading required for 100% eardrum rupture generally would be sufficient to severely injure or kill most animals (internal organ injuries).
>
> "The 50% eardrum rupture is statistically significant and correlates to ~30% incidence of PTS (Dr. Ketten, during SEAWOLF EIS review). This is a good indicator with a blank in the Table for the metric! Based on Yelverton-Richmond data, the SEAWOLF EIS used an energy flux density of 1.17 in-lb/in^2 as the criterion for 50% eardrum rupture. For conservatism, the SEAWOLF EIS used the total calculated shockwave energy in the direct, surface and bottom reflected pressure waves and did not limit the energy to 0.1 msec duration or apply a time limit related to the integration time of the ear." (notes from CD-NSWC/UERD)

and as:

> "At the acoustic criteria workshop hosted by NMFS 9-11 September 1998, NMFS posed several questions regarding the SEAWOLF approach to a panel of experts that included Dr. Ketten, Tyack Richardson etc. and which was attended by several environmental advocacy groups. The panel was asked to consider the following specific questions and they gave the following specific answers;
>
> "The Panel was asked whether they agreed with a 50% eardrum rupture as a criterion for explosion effects on marine mammals or whether a mitigation level of 10% was better. Dr. Ketten explained that she instructed the Navy, while they were developing the

> SEAWOLF EIS, to lower the eardrum rupture standard because they could not validate the 10%. Enough data exists about eardrum rupture in marine mammals to indicate that first, at 50% threshold level approximately 1/3 of the animals will experience TTS (sic). And second, that beyond this 50% pressure zone the occurrence of PTS is highly individualistic and variable, thus accurately extrapolating to 10% is impossible.
>
> "A few panel members mentioned that they felt 50% might not be conservative enough. Ken Hollingshead of NMFS emphasized the fact that for the SEAWOLF EIS the Navy assumed a full take within the 50% limit even though data indicates only 1/3 take at 50%. In addition, Dr. Ridgway remarked that SEAWOLF upped the mitigation limit to three miles from the previous two and he feels comfortable with that limit. Given the available data SEAWOLF conservatively uses the best available data."

The choice of the 50% rupture rate as criterion was thus based on statistical significance of deductions from the data, and not on a direct choice of rupture rate indicative of no physical injury (other than TTS). A 30% PTS incidence may not always be tolerable for a "no-injury" zone. The ratio of thresholds for 10% and 50% incidence is about 8. The energy level difference is thus about 9 dB, which is quite significant in the estimation of influence zones. [The estimated 'safety range was 3792 m for an animal at the bottom under the 10% criterion, and 1853 m for an animal on the bottom for the 50% criterion. Sensitivity of the range to animal depth is attributed to sound propagation properties rather than to depth dependence of the threshold.]

E.1.6 Eglin AFB Assessment (1998)

The thresholds for injury used in the subject risk assessment differ from those used in most Navy compliance documents for explosives. A positive impulse of 5 psi-ms is used, and the metric does not include the Goertner modification discussed above. Hence, this is a much more conservative (stringent) threshold than those used in previous assessments of the 1990s.

From the mine-clearance incidental harassment authorization (IHA) from NOAA/NMFS (1998):

> "Non-lethal injuries involve slight lung hemorrhage and tympanic membrane (TM) rupture from which the mammal is expected to recover (Yelverton et al., 1973; Richmond et al., 1973). Eardrum damage criteria are based upon a limited number of small charge tests (Yelverton et al., 1973; Richmond et al., 1973). Ranges for percent TM rupture incurred by underwater explosives can be calculated by a conservative TM damage model (U.S. Navy, 1996). General criteria for TM damage have been reported to occur at impulse levels down to 20 psi-msec (Yelverton et al., 1973).
>
> "Because eardrum (e.g., TM) rupture, rather than slight lung hemorrhage, usually occurs at lower impulse levels, TM rupture is used by NMFS and others to conservatively define the non-lethal injury zone. A maximum impulse of 10 psi-msec is often considered to define the non-lethal injury zone, where a very low incidence of blast injuries are likely to occur (Yelverton et al., 1973). A level of pressure impulse at which marine mammals are not expected to experience non-lethal injury (nor instantaneous mortality or lethal

injury) is reported to be 5 psi-msec (Yelverton et al., 1973). This is the impulse level adopted by the Air Force to designate no injurious takings by this activity."

E.1.7 Examples

Most Navy environmental compliance documents of the past ten years have used criteria and thresholds for injury based on the same data sources and analyses. Criteria for morality and various levels of injury are the principal differences among them. Examples are summarized in Table E.1-7

Table E.1-7. Criteria and Thresholds for Injury of Marine Mammals for Explosive Sources as Used in Recent Compliance Documents

TEST	CRITERION	THRESHOLD
SEAWOLF FEIS (1998)	Lethality from high peak pressure	Peak pressure 1400 psi (9660 kPa)
SEAWOLF FEIS (1998)	Lethality due to cavitation	Maximum horizontal extent of bulk cavitation region
SEAWOLF FEIS (1998)	Extensive lung hemorrhage (50% mortality) for a calf dolphin of 12.2 kg.	Impulse: 99.5 psi-msec (687 Pa-sec)
SEAWOLF FEIS (1998)	Onset of extensive lung hemorrhage (1% mortality) for a calf dolphin of 12.2 kg.	Impulse: 55.1 psi-msec (380 Pa-sec)
SEAWOLF FEIS (1998)	Brief physical discomfort	Partial impulse: 3.3 psi-msec (22.8 Pa-sec) within 0.035 msec
SEAWOLF FEIS (1998)	Onset of slight lung hemorrhage for a calf dolphin of 12.2 kg.	Impulse: 28.1 psi-msec (194 Pa-sec)
SEAWOLF FEIS (1998)	50% eardrum (tympanic membrane) rupture	EFD: 1.17 in-lb/in^2 (20.44 mJ/cm^2)
SEAWOLF FEIS (1998)	Tactile Perception	Pressure > 15 psi (104 kPa) and EFD > 0.01 in-lb/in^2 (0.18 mJ/cm^2)
SEAWOLF FEIS (1998)	TTS	182 dB* EFD Level: Greatest 1/3 octave band level for frequencies above 10 Hz for mysticetes and above 100 Hz for odontocetes (dual thresholds)
SEAWOLF (1998)	TTS	12 psi peak pressure (dual thresholds)
Florida Straits LOA(1994)	Safety radius is twice range for onset of slight lung hemorrhage for 100 kg mammal	Threshold for onset of slight lung hemorrhage for a 100 kg mammal is 25 psi-ms
Eglin AFB (1998)	'Safe" from physical injury	Positive impulse < 5 psi-ms
SSQ-110 EA (1995)	Harassment	176 dB* EFD Level (Total Energy)
DDG-53 LOA (1994)	Harassment	160-180 dB** EFD Spectrum Level #

EFD is Energy Flux Density * dB re 1 μPa^2-s ** dB re 1 μPa^2-s/Hz

Within the prescribed 'safety' zone, exposures to EFD spectrum levels in excess of 180 dB were estimated to occur in the band below 30 Hz and in excess of 160 dB in bands below 200 Hz. Under a spectrum-level criterion of 160 dB or 180 dB, animals that have hearing capability in the subject bands would be assumed to be harassed.

For a given threshold it would be useful to provide "safe ranges" for each case, as is done in Young (1991), Ketten (1995), etc. However, such estimates must inherently include estimates of the source properties and of the sound propagation. In the cases of Young (1991) and Ketten (1995), results are based on the theoretical, free-field propagation for an ideal explosive. These estimates and formulas are not likely to be valid in shallow water or at long ranges (relative to shot weight).

E.2 THRESHOLDS FOR NON-INJURIOUS HARASSMENT

This subsection gives background information on harassment thresholds for impulsive noise in water. Definitions of harassment and estimates of sound levels that cause harassment have evolved over the last ten years, and continue to change as more is learned about the sound files and animal reactions. The topic is complicated and little consensus can be found in the scientific community or from regulators.

E.2.1 Introduction

As mentioned several times, the term “harassment” has no statutory definition under the ESA and only a broad definition under the MMPA. Recall that under the MMPA, Level A harassment causes injury, while Level B harassment includes (paraphrase): any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or disturb a marine mammal by causing disruption of behavioral patterns, including migration, breathing, nursing, breeding, breeding, or sheltering.

Most environmental assessments for activities at sea involving underwater noise categorize risk to marine mammals in terms of (a) mortal injury, (b) non-mortal injury, and (c) Level B harassment. For one recent action, NMFS has distinguished between serious and non-serious injury in terms of eventual likelihood of mortality. Until 1985 or later, harassment was usually interpreted as a physical sensation felt by the animal. Hence, most assessments emphasized risks of the first two types, even though "safe" ranges are usually driven by Level B harassment criteria.

The selection of specific criteria for lethality, injury, and harassment is not guided by any formal guidance from NMFS, nor has Navy standardized its approach. For a single explosive event, Navy and NMFS have agreed in one case on criteria - those of the SEAWOLF Shock Trial FEIS (1998). There is, however, no indication that the guidance will not change for the next case. Also note certain inconsistencies in the subject criteria, in particular use of TTS for Level B, but not PTS for Level A.

See Section 3 and Appendix D for more on criteria for harassment and injury.

E.2.2 Examples

Whereas there has been much consistency among compliance documents of the past ten years for threshold for physical injury, there has been very little consistency in thresholds for (Level B) harassment of marine mammals and endangered species. Consider, for example:

Table E.2-1 Examples of Thresholds for Harassment and TTS by Explosives

Document	Source of Threshold: Threshold Level	Peak Pressure (dB re 1 μPa)	EFD (dB re 1μPa^2 s)
DDG 53 LOA (1995)	Richardson et al (1995): 160 to 180 dB SEL for Harassment. But EFD *spectrum* level of 160-180 dB used for zones.	*(220-240)*	185-205 [b]
DDG 53 LOA (1995)	As interpreted in the SEAWOLF FEIS (1998): 160 dB Peak Pressure for Harassment.	160	(125)
SSQ-110 (1995)	Harassment for Single Shot	*(211)*	176
SEAWOLF FEIS(1998)	Ketten (1995) for TTS: 5 to 15 psi Peak Pressure. [12 psi used for FEIS]	211-221 [219]	*(176-186) [184]*
Richardson et al. (1995)	Richardson et al (1995) auditory DRC fpr PTS	214-244	*(179 –209)*
SEAWOLF FEIS(1998) [b]	Richardson et al (1995) auditory DRC fpr PTS, modified for *SEAWOLF* FEIS [d]	241-250	*(206 –215)*
SEAWOLF FEIS(1998)	Ridgway (1997a) and Extrapolation by Helweg and Gaspin. TTS at 182 dB[a] for odontocete band (above 100 Hz)	*(232)*	197 [a]
SEAWOLF FEIS(1998)	Ridgway (1997a) and Extrapolation by Helweg and Gaspin. TTS at 182 dB [a] for mysticete band (above 10 Hz)	*(222)*	187 [a]

( ) Italicized numbers in parentheses have been extrapolated - based on an ideal shot of moderate size under ideal conditions. In that case the peak pressure level in the band is about 30 to 40 dB greater than the EFD level, provided that the reference unit for time is the second.

[a] The threshold listed in the FEIS is 182 dB (r e 1μPa^2 s) for the largest 1/3[rd] octave band level within the hearing band (above 10 Hz for mysticetes and above 100 Hz for odontocetes). This is about 5 to 10 dB smaller than the comparable total band level, depending on shot size, depth, range, etc. The values in the table are examples.

[b] DDG 53 LOA document uses 160-180 dB energy *spectrum level* as threshold for harassment. For the low band and the approximate spectrum of the shots used, the equivalent level in the low band (up to 1000 Hz) is about 205 dB (re 1μPa^2 s)

[c] The SEAWOLF FEIS (1998) disagreed with the DRC of Richardson et al. (1995)

[d] Richardson et al. (1995) estimate thresholds for PTS based on the amount that the peak pressure level of an impulse exceeds the human hearing threshold. This is a 'dynamic range' argument in which the observed range for humans in air is about 164 dB (log measure of a dimensionless ratio). Recall that the NRC(1996) paper suggests a range of 155 dB on the basis of human hearing. If dolphins had the same hearing range, then they would reach PTS at about 164 dB above their absolute hearing thresholds (40 to 70 dB re 1 μPa for a pure tone in white noise in the best hearing bands). Peak pressures of 214 to 244 dB (re 1 μPa) are thus proposed as possible thresholds for PTS.

E.2.3 TTS - *SEAWOLF* FEIS (1998)

In formal reviews of compliance documentation, NMFS often issues notices in the Federal Register covering responses to comments and issuing a "rule" which describes NMFS evaluation of the proposed action and specifies certain mitigation and reporting requirements. The

December 1998 announcement is especially relevant to this Appendix, since it addresses issues of criteria and thresholds.

In one application of the NMFS notice, the issue of whether TTS constitutes Level A harassment (slight injury) or Level B harassment (the usual interpretation) is resolved as follows in the notice for the final rule for the *SEAWOLF* Shock Test FEIS:

> "Therefore, the information provided in the FEIS supports the Navy's selection of temporary threshold shift (TTS) as a harrasment criterion for shock testing the USS SEAWOLF. NMFS concurs. TTS is being used as a measure of quantifiable harassment, as TTS may also result in behavior reflecting an adverse reaction, and TTS meets the definition of both Level A and Level B harassment definitions found in the MMPA. On a cellular level, TTS could be considered a very slight ``injury" in the sense of damage to hair cells in the ear and because TTS is temporary hearing loss, it could lead to a temporary disruption of behavioral patterns as specified in the statutory definition of Level B harassment. " (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

The use of TTS as the sole indicator of Level B harassment has also been at issue, as indicated in the following passage from the same Federal Register notice:

> "The 160-dB criterion [reference to the DDG 53 LOA] is based on a behavioral response which may be of questionable biological significance in the context of a single acoustic pulse. In the case of a continuous source (e.g., industrial noise) or repeated transient sources (e.g., seismic pulses), avoidance by a marine mammal could result in changes to migration, feeding, or reproduction patterns that could affect the energetics of both individuals and populations. However, in the context of a single, brief pulse from a detonation, a momentary startle response causing an animal to dive or momentarily change course or speed is not likely to affect either the individual or the population. Such a minor response is well within the range of normal behaviors that an animal might exhibit at any time in response to other animals or other environmental stimuli. As a result, NMFS does not normally consider these simple, singular, reflex actions (e.g., alert, startle, dive response to a stimulus) by marine mammals to be sufficient on their own to warrant an incidental harassment authorization. On the other hand, NMFS does not concur with statements made by the Navy in response to a different rulemaking that the term ``harassment" in the MMPA should be limited to changes in behavioral patterns of a magnitude that reflect an adverse reaction on the part of the animals such as intense fear or pain or behavior that is likely to harm the animal or its offspring. By statutory definition, the *de minimus* level (for Level B harassment) should be less intrusive on the animal than suggested by the Navy." (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

Neither for *SEAWOLF*, nor other assessments using TTS as criterion, are the degree or extent of TTS specified as part of the criterion. Conditions stated for the *SEAWOLF* FEIS are that the energy threshold be applied to 1/3-octave bands and to different parts of the spectrum for mysticetes and odontocetes (the former limited to the band above 10 Hz and the latter to the band above 100 Hz). This is included in the NMFS Federal Register notice.

As will be mentioned in subsequent parts of this Appendix, the Ridgway et al. (1997) paper is the basis for the threshold for SEAWOLF and at least one other compliance document (the AUTEC ER, 1998). The Ridgway paper documents temporary shifts in the masked threshold on the order of 5 dB for bottlenose dolphins subjected to 1-second tones. In applying the Ridgway result, the subject compliance documents are thus implicitly adopting the criterion of the Ridgway tests: a small (5 dB) shift in the masked threshold, where the masking field has spectrum level on the order of 25 dB above the absolute hearing threshold.

Of additional interest is the fact that most compliance documents do not link the criterion for TTS to any specific portions of the spectrum of hearing of the animals (other than the *SEAWOLF* FEIS removal of bands below 10 and 100 Hz for baleen and toothed whales, respectively). In particular, hearing loss at a single frequency or a small band of frequencies (e.g., 10 to 100 Hz or 3000 to 3500 Hz) has the same significance as the loss of hearing across a wide band. Threshold shifts of 5 dB are considered significant.

As standards evolve and research continues, issues related to this topic will undoubtedly be addressed.

E.2.4 Ketten (1995)

Ketten (1995) has been used as a source of information for criteria and thresholds for several compliance documents, including the recent SEAWOLF Shock Test FEIS (1998). Estimates for various effects on marine mammals for explosive energy are given on pages 402 to 404 of Ketten (1995). These estimates are based on the Lovelace data, data for humans in water, and on data for animals and humans in air. The estimates are given in the table below (with modifications for units and conversions).

Table E.2-2 Thresholds for Mammal Injury and TTS (Ketten, 1995)

Peak Pressure Units		Lethal	Mixed Lethal/ PTS	PTS >50%	Mixed PTS/TTS	TTS: Moderate to None
psi		1100	350-1100	100-350	15-100	5-15
dB re 1 μPa		258	248-258	237-248	220-237	211-220

Thus, according to Ketten (1995), to avoid harassment in the form of TTS, the peak pressure should not exceed about 5 psi or about 211 dB (re 1 μPa). The range from onset to mild TTS is 5 psi to 15 psi (211 to 220 dB).

For an explosive charge in a free field, the total energy (with second as time unit) in a wave resulting from a point explosive can be estimated at 30 to 40 dB below the peak pressure level (e.g., Cole, 1948). Hence, the total energy threshold corresponding to Ketten's "mild to modest TTS" can be estimated at 170-190 dB (re 1 μPa^2-s). To be consistent with application of thresholds for TTS in other compliance documents (e.g. SEAWOLF FEIS, 1998), these thresholds should be applied to the energy (or peak pressure) in the hearing band of the animal.

Note that the peak pressure level of 200 to 220 dB given in the assessment of Malme et al. (for air gun pulses) for avoidance is consistent with Ketten's peak levels for TTS. The extrapolated energy thresholds are not inconsistent with the SEAWOLF FEIS (1998) energy threshold for TTS (182 dB in 1/3 octave bands) or the SSQ-110 EA (1995) energy threshold for harassment (176 dB)

E.2.5 Baleen Whale Avoidance and Harassment for Air Guns (Malme, Richardson, and others)

Malme et al (1984) found that gray whales avoid areas where continuous low-frequency sounds exceeded 120 dB, but that pulsed sounds did not elicit a corresponding reaction unless the average intensity levels exceeded 160 dB (re 1 μPa).

Humpback, gray, bowhead, fin, and blue whales (all baleen whales) have been observed to continue their normal behaviors in the presence of air-gun impulses with peak pressures as high as 160 dB (re 1 μPa) (McDonald et al, 1993; Ljungblad et al, 1982). Avoidance reactions, however, were common when peak levels reached 170 dB (Richardson et al, 1986; Ljungblad et al, 1988).

Baleen whales have been observed to show some avoidance when noise pulses exceed 160-170 dB peak pressure (re 1 μPa).

E.2.6 Thresholds Used in the Eglin AFB Assessment (1998)

From Eglin AFB IHA (NOAA/NMFS, 1998)

"In addition to lethal, serious, and non-serious injury, harassment of marine mammals may occur as a result of non-injurious physiological responses to an explosion-generated shockwave and its acoustic signature. Based upon information provided in the SEAWOLF shock trial final environmental impact statement (U.S. Navy, 1998), a dual criterion for marine mammal acoustic harassment has been developed for explosive-generated signals: (1) An energy-based temporary threshold shift (TTS) injury criterion of 182 dB re 1 μPa^2-sec derived from experiments with bottlenose dolphins (Ridgway et al., 1997), and (2) a 12-psi peak pressure cited by Ketten (1995) as associated with a ``safe outer limit (for the 10,000 lb charge for minimal, recoverable auditory trauma'' (i.e., TTS)). For this activity, noise levels that fall between the 5 psi-msec and out to a transmission distance where a noise level of 180 dB re 1 μPa^2-sec"

E.2.7 Hearing Bands of Marine Mammals

For PTS, TTS, and behavioral reactions of marine mammals to noise, there is an underlying consideration of the hearing capabilities of a given animal and the importance of that capability. Consideration must be given to the small set of measurements of the absolute hearing thresholds of small odontocetes and pinnipeds, of the vocalizations of marine mammals, and of the observations of animal reactions to noise at sea. There are additional considerations, for behavioral reactions, of the ability of an animal to detect a sound in the presence of ambient noise or masking, and the significance of the frequency content of the sound to the animal. See Appendix J for additional information.

E.2.8 Ridgway TTS Study - Applied to Explosive Sources

As discussed above and in Section B.8, results of the TTS tests conducted by Ridgway et al (1997) have been applied in one case to estimate TTS thresholds for explosives.

The SEAWOLF FEIS uses the 192 dB SPL measured for tones above 3 kHz to estimate an energy threshold for all cetaceans. The approach of Helweg et al (1998) is to modify the 192 dB SPL, which caused a 5 dB shift in the significantly masked hearing threshold of dolphins, by the "integration time" (or "time constant") of a mammal (about 0.1 s). The resulting threshold is an energy level of 182 dB (re 1 μPa^2-s) applied to 1/3-octave bands above 10 Hz for baleen whales and 1/3 octave bands above 100 Hz for odontocetes. The application of an integration-time argument to hearing degradation caused by an impulsive source for marine animals is strictly theoretical and subject to study. The partition into 1/3-octave bands is also based on detection capabilities rather than on any correlation with stimuli that may cause hearing impairment. There is no precedent for the relationship between the narrowband signal level required to cause TTS and the energy level required to cause TTS.

E.2.9 MMS/ITM (1998) Workshop: HESS Committee Findings for Thresholds

Seven key recommendations were given. Most notable (and the one which Pierson said occupied the most time and effort) was the sound level at which problems might occur (such as harassment). The estimation of the threshold was driven by Ketten, but agreed upon by all. The threshold, for impulse sound, is an rms pressure level of 180 dB re 1 μPa. This level is to be applied to all mammals and seismic impulses. {No allowance is made for the frequency spectrum of the sound and the hearing sensitivities of the animals. In addition it is important to note that in most cases the rms pressure level lies between the energy flux density level (with second as the time reference) and the peak pressure. A typical relationship might be 170 dB (re 1 μPa^2-s) energy, 180 dB rms (re 1 μPa), and 195 dB (re 1 μPa) peak pressure.}

{There is a problem with rms pressure levels for sound waves generated by impulsive sources. Richardson noted this in his talk, and gave an example. Underwater sound signals are usually measured in terms of intensity (which is proportional to mean-square pressure for non-impulsive sound), peak pressure, or total energy (energy flux density). The latter two are the usual metrics for impulsive sounds. rms pressure depends on how one determines the duration of the signal; peak pressure and energy do not. Mean-square pressure is proportional to energy divided by the averaging time for the mean-square.

For simple impulses without multipath,

$$(\text{peak pressure})^2 > (\text{rms pressure})^2 > (\rho c)(\text{energy flux density})$$

For an ideal explosive in a isospeed halfspace, the similitude equations (Cole, 1948) can be used to calculate the relationships}

APPENDIX F.
BACKGROUND ON THRESHOLDS FOR IMPACT OF UNDERWATER, NON-IMPULSIVE NOISE ON MARINE MAMMALS

This appendix provides background and miscellaneous materials relevant to Section 5 of this report. It has two parts, this first (F.1) on injury and the second (F.2) on non-injurious harassment.

F.1 THRESHOLDS FOR INJURY

Non-impulsive (continuous, persistent) noise is not known to cause non-auditory physical harm to marine animals, principally because the large peak pressures are almost never present. Note, however, that adverse physical effects are suspected for human divers exposed to low-frequency tones (below about 1000 Hz). These effects include possible lung resonance vibrations and inner ear disturbances. "Safe" levels for experienced and amateur divers have been established on an interim basis by the Navy at 150 dB (re 1 μPa) and 130 dB, respectively (see, e.g. ProPatria II, 1997). Whether or not marine animals suffer similar effects is not known. Recent Navy compliance documents have used thresholds for non-auditory injury in the range from 180 dB to 210 dB (re 1 μPa)

There are three conditions for which some injury to marine animals from non-impulsive noise has been suggested:

PTS for noise in the hearing band of the animal

LOW-FREQUENCY NOISE and possible physical injury related to vibration/oscillation processes

MID-FREQUENCY NOISE AND BEAKED WHALES (suggested by two stranding events in which tactical active sonars have been suspected as cause).

ATOC (1995) and SURTASS-LFA DEIS (1999) have addressed the possibility of harm to marine life from low-frequency sound. Otherwise, there is no recognition of significant non-auditory impact from projectors used in the Navy.

There have been no controlled measurements to determine PTS or other physical injuries to marine life from projector signals. The usual approach (e.g., NMFS, 1995) is to assume that marine mammal ears have about the same range of reactions as human ears, so that thresholds of pain, for example, can be estimated from the absolute hearing threshold of the mammal and the increment required to cause pain in humans. With such an approach, damage to the ear is estimated to occur at about 150 dB over hearing threshold (NRC, 1996; Ketten, 1995; Richardson et al, 1995). For a small toothed whale or pinniped, the best absolute hearing thresholds are on the order of 40 to 70 dB. Thus, the sound level at which some harm may begin to occur, according to this approach, is about 190 to 220 dB.

As noted above, sustained exposure to levels as high as 190 dB would typically require the animal to remain within 500 m of one of the Navy's more powerful sonars while the sonar is transmitting.

Note on Non-Auditory Injury to Marine Mammals Caused by Non-Impulsive Signals

As is often done for explosive sources, classify the effects of non-impulsive noise on marine mammals into three categories: (1) Hearing Effects, (2) Physical Injury Not Related to Hearing, and (3) Behavioral Effects. Category (1) includes both permanent injury and temporary impairment (both Level A and Level B Harassment). Category (3) is usually treated as a non-injury effect, and hence as Level B Harassment. Category (2) fits the definition of Level A harassment, and is the subject of this note.

Most of the emphasis in research on the effects of non-impulsive noise on marine mammals has been in the areas of categories (1) and (3): hearing impact (especially TTS, ATS, PTS) and behavioral response. TTS has been used as an indicator of Level B harassment, and has been endorsed by NMFS in at least one case (SEAWOLF FEIS, 1998) as the sole indicator of Level B harassment. NMFS has from time to time treated TTS as an indicator of Level A harassment as well (e.g., SEAWOLF FEIS).

Projectors, even those as powerful as the SURTASS-LFA or AN/SQS-53 sonars, have not been known to cause non-auditory physical injury in marine mammals. Whereas the smallest explosives can cause serious injury at range, projector signals do not exhibit the peak pressures and broadband, impulsive waveforms of explosive signals. The peak pressure referred to one meter will not exceed 250 dB for the most powerful sonar array (which itself has dimensions of several wavelengths), while a 1.8 pound SUS charge has peak pressure of order 260 dB at one meter.

In tests on dolphins and beluga whales, Ridgway et al. found that levels in excess of 200 dB for short mid and high-frequency tones caused no physical harm, except TTS. In attempts to simulate impulsive signals, acoustic projectors produced peak levels as high as 220 dB without any TTS or other physical impact.

Richardson et al (1995) state that, "We have seen no reports demonstrating whether high levels of steady or impulse noise cause "discomfort" or nonauditory physiological effects in marine mammals."

NRC (1996) has a subsection dedicated to " Potential Nonauditory Acoustic Effects on Marine Animal Health." This follow-on to the 1994 NRC report on low-frequency sound impact mentions only the Crum and Mao (1996) and Lettvin et al (1982) studies on bubble growth in tissues caused by exposure to intense, low-frequency sound. In that case, it is hypothesized that marine mammals may be injured when exposures exceed 210 dB (re 1 μPa) SPL for at least several seconds. This is a theoretical result and there is no evidence that such an injury may actually occur in either humans or animals.

Cudahy and others presented on overview of non-auditory physiological impact to human divers from low-frequency projectors at the ONR Workshop (1998, Proceedings in process). Some of this work was in support of the LFA system. From the most recent draft of the ONR report (April 1998), two statements are relevant:

Diver Exposure Limits for LF Sound "It [NAVSUBMEDRSCHLAB, 1995] gave the maximum level as 160 dB for a 100 second signal between 160-320 Hz for a total of 15 minutes with a maximum 50% duty cycle."

Diver Non-auditory Sensing of LF Sound. "The Navy Environmental Health Center (NEHC, 1997) specified that 130 dB SPL at dives sites was the maximum level used in the current sea research program. This number was based on the minimum threshold for vibrotactile sensing of an underwater sound between 100 and 500 Hz.

The table below summarizes the various thresholds given above:

Table F.1-1 Thresholds for Injury for Non-Impulsive Noise

Exposure SPL (dB re 1 μPa)	Exposure Time	Effect	Reference
210	seconds?	injury caused by bubble growth in tissues low frequency signal	Crum and Mao (1996)
160	100-second signals, over 15 minutes at 50% duty cycle	"safe" exposure level for divers and LF signals	NAVSUB-MEDRS-CHLAB (1995)
130	seconds	sensing by diver of low-frequency signals	ONR Workshop (1998)
202? – 230?	one second	proposed onset of PTS for mid-frequency signal (based on 10 dB above mid-level TTS)	Ketten at NMFS (1998)
237 (peak pressure)	single explosive signal	"safe" level for divers	Christian and Gaspin (1974)

F.2 NON-INJURIOUS HARASSMENT

General Remarks on Harassment Thresholds

Harassment of marine mammals includes significant disruption of habitat, feeding or migration patterns, etc. Various thresholds for the amount of noise it takes to cause harassment have been hypothesized. Because marine mammals depend so much on their hearing, noises that degrade hearing sensitivity may be lethal. The effects of noise include permanent threshold shifts (PTS), temporary threshold shifts (TTS), masking of predator noises, masking of communications, interference with search for food, annoyance, etc.

Certain marine animals are known to depend on their hearing for everything from protection from prey to feeding, mating, and communicating. Essentially all cetaceans (whales and dolphins) are in this category, as are sirenians , some pinnipeds, and some sea turtles. It is widely believed that even temporary degradation in hearing ability may lead to injury or death.

The estimated risk of harassment to marine mammals depends greatly on the threshold used. The range of possibilities (120 to 200 dB for tones, and 160 to 220 dB (energy) for impulses) corresponds to the difference between undetectable and deadly. Even if the uncertainty is 20 or 30 dB, the differences in unsafe areas, "take" estimates, and mitigation requirements are vast.

Because most of the indicators of harassment interpreted for the Marine Mammal Protection Act (MMPA) are difficult to measure and quantify (masking, interference, avoidance), the Navy and NOAA/NMFS have focused on one of the indicators which can be objectively measured: temporary loss of hearing sensitivity or "temporary threshold shift" (TTS). The emphasis on TTS came about as a result of the SEAWOLF Shock Test Final Environmental Impact Statement (1998). Navy and NOAA/NMFS cooperated in an effort to establish reasonable mitigation procedures for a test deploying 10,000 pound (TNT) explosives in shallow water.

The Navy and Air Force have taken the position at times that TTS is an defensible indicator for marine mammal harassment. NOAA/NMFS recommended in 1995 (on an interim basis) the use of pure-tone levels 80 to 100 dB above absolute hearing threshold as harassment levels based on annoyance or TTS (see the ATOC FEIS: ARPA, 1995a and 1995b). Absolute hearing thresholds for marine mammals in the band of sensitive hearing tend to fall in the range 40 to 80 dB (re 1 μPa). See Richardson et al (1995) for examples of audiograms for pinnipeds and cetaceans. The NOAA/NMFS thresholds of choice are then in the range from about 120 to 180 dB (re 1μPa), depending on the species and frequency.

'Safe' levels in recent use for TTS for marine mammals are on the order of 160 dB (re 1 μPa) for a single-frequency tone of long duration in the band of the animal's sensitive hearing. Signals of short duration may be less harmful and are sometimes given a "credit" of between 10log(T/t) and 13log(T/t) where T is the total time and t is the amount of time the signal is actually on.

Past risk assessments have often made a distinction among marine mammals according to their hearing bands (frequency bands of sensitive hearing). As discussed in Appendix I, marine mammals are sometimes divided into two classes:: those that have their most sensitive hearing at lower frequencies (e.g., below 1000 Hz) and those with their most sensitive hearing at higher frequencies. In the case of aircraft noise, a majority of the acoustic energy will usually be found in the band below 1000 Hz. That class of interest is believed to include the mysticetes, certain pinnipeds (California sea lion, elephant seal), and the sperm whale. It may also include some mid-size odontocetes.

Review of Historical Threshold Levels for Harassment by Non-Impulsive Noise

120 dB, 140 dB, 160 dB

As discussed in the National Academy of Sciences report (NRC, 1994), a tone-like noise at a level of 120 dB (re 1 μPa) was found to cause behavioral changes in mysticetes for two cases documented by Malme et al (cf Richardson, 1995).

160 dB

By this timeframe (1994), the zone view had been expounded upon by Richardson et al (LGL in 1991 and text 1995). The result evolved into the three Zones of Influence: Zone of Audibility, Zone of Behavioral Modification, and Zone of Potential Impact (as used in several EAs, most notably LFA 13). Thresholds associated with these zones were 120, 140, and 160 dB (re 1 µPa) respectively. Here the threshold applies to SPL (or intensity level) for a narrowband, long duration signal. The Zone of Potential Impact was implicitly considered the zone of harassment.

150 dB

In this timeframe, the ATOC EIS was litigated and, in spite of a benign source, the case was lost. The NAS study listed above was begun in response to ATOC issues. It is important to note that the low frequency ATOC source level was 195 dB (re 1 µPa at 1 m) and that the threshold for purposes of harassment was 150 dB (SPL for a narrowband signal, dB re 1 µPa). A 45 dB transmission loss will generally be achieved prior to about 180 m (as long as the water depth is at least 400 m).

160 dB

The recently approved ProPatria 2 EA uses the same text as used for ATOC to justify a 160 dB harassment level for the LFA source.

120-160 dB

From time to time NOAA/NMFS has stated a preference for 120 dB. They have also gone on record with a threshold tied to the hearing threshold of the animal, being some 100 to 120 dB above the threshold. For most odontocetes, this converts to something in the 160 dB range (for tones above 2000 Hz), and for some pinnipeds, 10 to 20 dB higher. We can only guess mysticete thresholds, but a harassment threshold of 160 dB has been used.

160-175 dB

Until July 1997, the Navy had used a threshold exceeding 160 dB for tonal harassment only once. Based on experience for humans and quoting Kryter, the document noted that a minus 10 log (cycle) could raise the threshold, where 'cycle' is the fraction of the time the source operates. Thus, if a projector were on 30 seconds and off 30 seconds, under this theory, the threshold would be raised by 3 dB. The scientific or regulatory communities have not accepted this approach generally. On the other hand, it is probably fair to make some allowance for the case in which the signal is not long-term.

190-200 dB

In Summer 1997, PEO(USW) sponsored a TTS study by Ridgway et al. of NRaD. The study linked thresholds for harassment to TTS (based on being able to measure TTS objectively and the fact that other criteria for harassment are not easy to quantify). The. study results show thresholds for TTS for captive bottlenose dolphins in masking noise to be 190 to 200 dB (re 1 µPa) for 1-second tones in the 3 to 75 kHz range. These thresholds are approximately 30 to 40 dB above any used in formal compliance documentation (i.e., in decisions on applications for take authorizations) for projectors.

120-200 dB

In the past two years, thresholds have varied over the whole range of possibilities. With more research has come more variation. The MMRP and LFA-SRP have suggested to some a threshold of 120 dB for long term exposure to low-frequency noise. The same is true for mid-frequency noise, given a higher threshold for short exposures (e.g., 190 dB), but a much lower one for long term exposure.

Thus, in just a few years the threshold for harassment of cetaceans by "continuous" signals (projectors, sonars, machinery) has varied from 120 to 160 to 150 to 175 to 160 to 200 to 120 dB (all re 1 μPa). The table below illustrates the spread of values used in the past.

Table F.1-2. Historical References for Criteria and Thresholds for TTS and Harassment Caused by Non-Impulsive Noise for a Single Event

Effect (Criterion)	Marine Life	Signal Type	Frequency Band	Metric	Threshold (dB re 1 μPa)	Reference
"Behavioral Changes"	dolphins	tone (1 sec)	3-75 kHz	SPL	186-178 dB	Ridgway et al. (1997)
TTS of 5 dB in masked threshold	dolphins	tone (1 sec)	3-75 kHz	SPL	200-194 dB	Ridgway et al. (1997)
Harassment	mammals	continuous	hearing band	SPL	150 dB	ATOC (1995)
Harassment	mammals	continuous	hearing band	SPL	160 dB	NMFS, post-ATOC (1995)
"Behavioral Changes"	mammals	continuous	hearing band	SPL	140 dB	NMFS post-ATOC (1995)
Avoidance	baleen whales	continuous	<1000 Hz	SPL	120 dB	Malme et al (1984)
'Behavioral Reactions'	mammals	narrowband	hearing band	SPL	70 dB above absolute hearing threshold	NRC(1996), from NMFS
Annoyance or TTS	mammals	narrowband	hearing band	SPL	80-100 dB above absolute hearing threshold	NRC(1996), from NMFS
PTS (included for comparison)	mammals	narrowband	hearing band	SPL	155 dB above absolute hearing threshold	NRC(1996), from NMFS

Two Notable Compliance Actions That Do Not Use the Ridgway Results

It must be mentioned here also that there are two highly visible Navy compliance actions in process that do not use the Ridgway results. The main reason is that the frequencies of the

acoustic signals are below 500 Hz, well below the lowest frequency tested in Ridgway (1997). It is known from direct measurements of hearing that small toothed whales have much less sensitivity at the low frequencies than at those above about 2 kHz - so that the Ridgway results are difficult to extrapolate.

Both compliance actions are different from the ECSWTR case not only because their sources are low-frequency projectors, but also because the sources are stationary or slowly moving.

The first case is the SURTASS-LFA DEIS which uses the Ridgway results for its high-frequency 'whale-finder' sonar, but not for the LFA system itself. For LFA, the threshold for Level A harassment for all mammals (including toothed whales) is 180 dB. For Level B harassment, the criterion is behavioral reaction and the threshold is stated as an expected percent of animals harassed at each level (e.g., none at 120 dB, 3% at 150 dB, 50% at 165 dB, 100 % at 180 dB) for a single ping. For multiple pings, the threshold is reduced at the rate of 1.5 dB for every doubling of the number of pings. For the LFA source in typical ocean areas, the same number of takes would be counted if the single-ping threshold were about 160 dB. However, since the LFA system is so powerful, the multiple-ping effect can be substantial, and for a multi-day mission the equivalent threshold as low as 145 dB. If ECSWTR were to use this approach, the 'take' estimate would increase by a factor of 10 or more, with a number of Level A 'takes.' Note that the SURTASS-LFA is the first Navy sonar system to prepare a compliance document and seek a harassment permit for operational use. The operational SURTASS-LFA system is under Pacific Fleet control.

The second compliance action is for the ONR NPAL (North Pacific Acoustic Lab), which uses the fixed (moored), ATOC source in Hawaii. A 'take' permit is being requested, for a projector with a 195 dB (re 1 micropascal at 1 m) source level and with a very small duty cycle. Without having reviewed the document, it is only surmised that the Ridgway (1997) results are not used, since multiple takes are predicted and a permit is being sought for this extremely low-power system. This is also a Pacific Ocean action.

Low-Frequency --- Criteria and Thresholds for Level A and Level B Harassment for SURTASS-LFA

There are no direct measurements for large (baleen and sperm) whale hearing sensitivities or for impact of noise on their hearing. Likewise for all but the small odontocetes. There are data for some pinnipeds. Except perhaps for isolated cases, it is not known how or if any of these animals use sound energy in the 200 to 500 Hz band, or if they might react to an LFA signal. Hence, in the frequency regime for LFA, criteria for harassment and thresholds for harassment are based for the most part on indirect evidence (e.g., call frequencies, observed avoidance in the field). Especially important is the threshold as a function of exposure time, for which there is little known.

For the LFA system waveforms (frequencies and durations), a reasonable, middle-of-the-road threshold for Level B harassment is sought. Based on historical and largely indirect measurements [as summarized by Richardson (1995)], and on preliminary findings of the LFA-SRP, thresholds that address behavioral impact on large whales are suggested as follows:

- For a single exposure of up to 10 seconds, the intensity level (rms pressure level, SPL) for Level B harassment would be 180 dB (re 1 μPa).
- For long term exposures of several hours or more, a threshold of 160 dB (re 1 μPa) is not inconsistent with data and past usage (e.g., ATOC threshold for continuous transmissions was 150 dB.)
- An equal-energy type of interpolation from 180 to 160 would be consistent with some experiences in human hearing. [A "(5/3) energy" approach as taken at the NMFS workshop by Gisiner-Schusterman-Ridgway-NIOSH-Ketten would likely cause LFA to seek Level A take permits for any and all activities].

For odontoncetes (except sperm whales), pinnipeds, and manatees, it is expected that absolute hearing thresholds will be greater for the LFA band than for the bands of best hearing. Nonetheless, a number of experts in the community (Ridgway, Gisiner, Hellweg, etc.) have argued that the reduced hearing capabilities of these animals in the LFA regime does not prevent behavioral reactions (since the animals are likely to hear the signals). Hence, the same thresholds given above would apply.

Ketten (NMFS Criteria Workshop, 1998) recommends thresholds for PTS of about 200 dB (re 1 μPa) for a 1 second tone, 190 for 4 seconds, 180 for 16 seconds, 170 for 64 seconds, 160 for 256 seconds, and ...130 dB for 6 hours or more. These thresholds (which incorporate the Gisiner-NIOSH slope and 10 dB threshold increment for PTS over TTS) are so low as to cause even modest projectors to present a serious risk of Level A harassment. Any use of these thresholds must be avoided on the rationale (1) the slope is based on human hearing over long durations, (2) Ketten's estimate of PTS stimulus at 10 dB above TTS stimulus is based on terrestrial mammal hearing and does not account for the amount of TTS suffered, and (3) neither of the two data points on the curve (Ridgway TTS and Schusterman TTS) have received critical reviews, not are they published.

In summary, thresholds for marine mammals and sea turtles for behavioral harassment are suggested as follows:

180 dB for a 1 minute exposure
177 dB for 2 minutes
174 dB for 4 minutes
171 dB for 8 minutes
168 dB for 15 minutes
165 dB for 30 minutes
162 dB for one hour
160 dB for more than two hours

Decibel quantities are total SPL referred to 1 μPa. "Exposure Time" is roughly defined as the time over which signals arrive at the animal with a density of one every several minutes.

Low-Frequency -- NRC (1996) Report on Low-Frequency Sound

In revisiting the 1994 NRC study, the expert panel made provided information and opinions directly relevant to the criterion and threshold question for mammals:.

"Specifically, the Committee believes that regulations must focus on activities that significantly disrupt behavior critical to marine mammal survival and reproduction." (Executive Summary, page 2)

On page 18,

"The Committee supports this effort to distinguish between injury and disruption of behavior. For acoustic harassment, measurement of TTS may provide a conservative estimate of safe exposure levels with regard to injury (Level A above). Thus, sounds with intensities lower than those expected to produce TTS should be considered noninjurious."

"The Committee believes that it does not make sense to regulate minor changes in behavior with no adverse impact; rather, regulations must focus on significant disruption of behaviors critical to survival and reproduction, which is the clear intent of the definition of harassment in the MMPA."

"The Committee believes that NMFS should regulate all effects of sound on marine mammals on the same basis: their biological significance."

And on page 19:

"NMFS has set the following guidelines for SIT authorizations for research of other activities having the potential for acoustic harassment. These guidelines are used to decide, when there is no information to the contrary, sound levels that would not be expected to have the following effects:

70 dB above a species' hearing threshold constitutes a level that would elicit behavioral reactions;
80 to 100 dB above threshold are levels that create annoyance or a temporary threshold shift; and
155 dB above threshold would lead to a permanent threshold shift. "

"... These standards were based largely on observations of human hearing and effects of sound. Results from human hearing in air cannot be extrapolated to humans underwater (Smith, 1985; Smith et al.. 1988), so observations of human hearing abilities in air are even less likely to be appropriate for marine species. The Committee heard recent results from the first TTS study in a whale, and the above standard is lower, by a factor (sic) of more than 45 dB, than actual observations."

Low Frequency -- HIFT, ATOC and 120 dB Threshold for Avoidance

While not a published document, the Kineon (1996) dissertation offers historical information on thresholds such as:

Regarding the Heard Island Feasibility Test (HIFT), "The initial permit request stated that the sound produced by the HIFT source would attenuate to levels of 120 dB at 40 km from the source." (Heard Island Environmental Assessment, National Ocean Service, 1990). "One hundred and twenty decibels is the level at which gray whales in a few studies were seen to veer away from the sound source. This became the recommended level for NMFS to measure harassment for this type of sound source (Watkins and Tyack, "Biological Impact of Heard Island Experiment on Marine Mammals," comments on the Heard Island EA, 1990), there is little other documented behavior results of marine mammals to constant sound sources. Calculations and test results after HIFT confirmed that the zone of influence was 1000 km, not the original 40 km." (SCIENCE, **252**, 914, 17 May 1991) (Kineon, 1996, page 47)

TTS -- Studies of Ridgway et al. (1997)

A TTS measurement program was initiated by the Navy in 1996 and the first results released in the spring of 1997 (Ridgway et al, 1997). Note that this was the *first TTS test* ever performed on whales (including dolphins). Although the report is still in review, this author has submitted notice to the Navy (CNO-N45) that the results are most certainly flawed and that little can be learned from the multi-month test involving four captive bottlenose dolphins. If nothing else, the following very weak statement may eventually be shown to be correct for some limited set of animals and conditions:

(A) For toothed whales (odontocetes), the best hearing sensitivities have been found to be in the range from about 10 kHz to 90 kHz. Measured hearing thresholds over the years indicate levels for pure tones of 40 to 70 dB (re 1 μPa) in the frequency band mentioned. Outside of the band, toothed whales are nearly deaf, with thresholds far above ambient noise, in the vicinity of 100 to 200 dB. (All of this was known before the TTS test).

(B) Complications of the test, especially the addition of masking noise, precluded the determination of sound levels at the onset of threshold shifting. Behavior of the animals was difficult to interpret under a captive/reward environment. The most conclusive results for the effect of 1-second tones at 3 kHz, 20 kHz and 75 kHZ are that the animals have significant behavioral changes at levels of 180 to 190 dB (re 1 μPa) and large (50 to 70 dB?) TTS for tones of order 190 to 200 dB. Nothing can be said about discomfort, pain, TTS, etc for levels less than about 190 dB.

(C) For reference, the numbers reported are:

TTS: 194-201 dB at 3 kHz, 193-196 dB at 20 kHz, 192-194 dB at 75 kHz.
Change in Behavior: 186 dB at 3 kHz, 181 dB at 20 kHz, 178 dB at 75 kHz

The TTS results may be useful in identifying tone levels at which we can be certain of serious harassment or injury to small odontocetes. The results do not indicate the levels at which harassment begins, nor are the results applicable to baleen whales. The results may also not be applicable to other odontocetes , pinnipeds, or sirenians.

TTS --- Studies of Kastak et al. (1999)

A second Navy TTS study was conducted by Kasak et al. (1999) on pinnipeds (seal and sea lions).

The tests are not directly related to the Ridgway tests, since they were conducted in a quiet pool and the stimulus noise consisted of 20 minute, octave-band signals in the vicinity of 1000 Hz. Results indicated the onset of TTS (5 dB of hearing loss) for signals in the 135-145 dB range (re 1 μPa).

Multiple Exposure Rules

Ridgway and others (including NOAA/NMFS at the NMFS Workshop in 1998) have hypothesized a level-time relationship for TTS based on the two data points (Ridgway and Kastak). The rule proposed begins with a threshold of about 192 dB for a one-second continuous signal and reduces the threshold by 5 dB for every doubling of exposure time (or number of exposures). Thus, for example, a 16-second tone at a level of 172 dB would cause the same TTS effect as a one-second signal at 192 dB. The rule is related to a dated NIOSH relationship for long-term human exposure to broadband noise, and is sometimes represented as a "17 log T rule." Compare this to the "duty cycle" rule mentioned above, and to the various other rules found in human hearing studies (especially the 'equal energy' rule: 10 log T). The 17logT rule has serious negative ramifications for risk assessments in that 120 dB (the lowest threshold considered) is reached within about five hours.

The possibility of PTS at 10 dB above TTS has been suggested by Ketten (1998) in the same NMFS Workshop. Adoption of this threshold has even more serious implications for risk assessments - resulting in injurious ("Level A") takes at low exposure levels (e.g., 130 dB for multiple hours).

Behavioral Changes - Overview

Under the Marine Mammal Protection Act (MMPA), it is illegal to harass marine mammals, where "harass" is interpreted as everything from causing them to leave the area to changing their feeding behavior. Sound waves (both in air and under water) have been cited in a number of observations as causes for harassment.

Whereas sound of sufficient strength to cause hearing problems under water may be in the 160 dB range for continuous tones, current thinking is that continuous tones with 140 dB intensity may cause behavioral changes and possible harassment. For broadband energy, there is little agreement, but 150 to 156 dB energy density may be appropriate.

There is an additional concern about "masking," that is, producing noises of sufficient strength above ambient to prevent animals from detecting sounds vital to their livelihoods. There is very little known about the threshold levels and effects of masking.

Behavioral Changes -- Observations of Avoidance for Baleen Whales

Malme et al (1984) found that gray whales avoid areas where continuous low-frequency sounds exceeded 120 dB, but that pulsed sounds did not elicit a corresponding reaction unless the pulsed levels exceeded 160 dB (intensity, re 1 μPa).

Humpback, gray, bowhead, fin, and blue whales (all baleen whales) have been observed to continue their normal behaviors in the presence of air-gun impulses with peak pressures as high as 160 dB (re

1 μPa) (McDonald et al, 1993; Ljungblad et al, 1982). Avoidance reactions, however, were common when peak levels reached 170 dB (Richardson et al, 1986; Ljungblad et al, 1988).

Behavioral Reactions -- Observed in Ridgway et al (1997) Tests

In conducting the TTS tests on dolphins discussed above, Ridgway et al (1997) observed significant behavioral reactions from the animals at levels much lower than those required to cause measurable masked threshold shifts, ranging from about 178 to 186 dB for frequencies above about 3 kHz.

As a result, the Navy community has tended since 1997 to use the levels that cause the behavioral reactions in Ridgway's tests as thresholds for harassment from a continuous source of duration about one second. These thresholds are usually applied to all small odontocetes, but also sometimes to all whales (e.g., SEAWOLF Shock Test FEIS, 1999).

Levels of 180 dB have been used for the single-ping harassment level for the LWAD Environmental Assessments (LWAD 99-01, 99-02, 99-03), and a number of other Navy sonar tests. These assessments have been approved in Section 7 consultations with the regulators (NOAA/NMFS).

As an example of the diversity, consider the thresholds for harassment used in the Navy's recent SURTASS-LFA DEIS (1999). For low-frequency, continuous sound (below 500 Hz) of duration less than 100 seconds, the threshold is represented as a statistical quantity defined by a function similar to a normal distribution function. The approach states that no animals are harassed at 120 dB, 2.5% are harassed at 150 dB, 50% at 165 dB, 95% at 180 dB, etc. Injury is assumed to occur at 180 dB. While the risk function appears to be reasonable at first sight, note well that the symmetry of the function in decibels leads to the distressing result that in regions of good sound propagation the small-percentage takes dominant those at the higher levels (i.e., 2.5% of the animals exposed to levels of 150 dB or more can exceed 50% of the animals exposed to 165 dB).

Overview of Thresholds for Estimating Harassment Impact of Tactical Hull-Mounted Sonar Signals on Marine Mammals

Technical Evidence

For most compliance issues involving underwater sound, the "science" is not adequate to justify use of one harassment threshold over another. However, the "science" that Navy has developed on harassment of whales/dolphins is directly applicable to the tactical sonar and ECSWTR scenarios: namely, the Ridgway et al (1997) tests on bottlenose dolphins (hereafter referred to as 'Ridgway (1997)'). The Ridgway (1997) study was designed for exactly the case of interest: the effect of mid-frequency and high-frequency sound sources (especially sonars) on small odontocetes (represented by bottlenose dolphins, among the most plentiful of marine mammals in the planned ECSWTR area). The results of the Ridgway study have been embraced and widely promulgated by PEO(USW). They have been applied to a number of compliance documents, including the Environmental Assessments for ONR's LWAD test series, the AUTEC ER (for mid-range sonars), and the SEAWOLF Shock Trial FEIS. While there are issues in the Ridgway (1997) study regarding the use of masked thresholds and about behaviors of captive

dolphins, there is one result that was repeatedly and consistently obtained: significant TTS for a one-second tone at sound pressure levels above about 190 dB (at 3, 20, and 75 kHz). Since TTS is a physical effect, it can be directly and objectively measured. The result is repeatable, and the degree of impact is only weakly dependent on the predisposition of the animal and its training.

If there is any complaint about the Ridgway results, it is that the TTS thresholds are too high (i.e., that TTS may actually occur for 1-second stimulus signals with levels below 190 dB) - if they are to be interpreted as levels for the 'onset' of TTS. This complaint was recently restated in the SURTASS-LFA DEIS (1999) and in the Kastak-Schusterman et al (1999) article in the Acoustical Society journal on TTS for seals and sea lions.

What the science does say, then, is that TTS (a form of harassment, according to NMFS) is very likely to occur in dolphins exposed to short tones at levels above about 190 dB (re 1 micropascal) and at frequencies near 3, 20 and 70 kHz. To be precise, the results of the testing of four dolphins over many months are usually summarized as:

> TTS: 194-201 dB at 3 kHz, 193-196 dB at 20 kHz, 192-194 dB at 75 kHz.
> Change in Behavior: 186 dB at 3 kHz, 181 dB at 20 kHz, 178 dB at 75 kHz

For example, this means that a 3 kHz, 1-second tone signal with (received) intensity level in the range from 194 dB to 201 dB was found to cause TTS in the dolphins tested.

There remain some questions about the accuracy of the Ridgway (1997) TTS results, concerned primarily with the interpretation of the 'onset' of TTS when measured in a noisy environment. The stimulus level to cause small amounts of TTS may be lower than 190 dB. However, there is no question that some amount of TTS will occur at 190 dB. In recognition of this issue, it makes sense for the interim to use 190 dB as an 'upper limit,' and a lower threshold for Level B harassment. This issue was addressed in the ECSWTR DEIS by using a value of 180 dB for a single sonar ping as the harassment threshold. The number is based on the observation in Ridgway's (1997) tests that the subjects showed significant behavioral reactions (e.g., avoidance) to tones at levels near 180 dB. Although precise interpretation of behavioral responses of trained, captive animals is not without risk, after viewing the video tapes of the tests, most observers agree that the dolphins were reacting negatively.

For a dolphin and a mid-range sonar, it is thus reasonable to expect that a short ping of received level above about 190 dB will cause measurable TTS, and a short ping of level above about 180 dB can cause behavioral reactions. It is very important to notice here that the difference in sound levels that cause the two effects is only about 10 dB (the same order of decibel spread as expected for measurements of the sound field at range). Either effect might be termed 'harassment,' but the point is that the 'science' tells us the sound levels for which behavioral reactions and measurable TTS can be expected.

To this point, only single exposures of animals to short, tonal signals have been addressed. For the tactical sonar problem, research on the impact (TTS or behavioral) of longer duration signals, multiple exposures over time, coded waveforms, etc. is only now being considered. There are no direct measurements of TTS for whales/dolphins. To account for the impact of multiple pings or

pings of duration greater than one second, most risk assessments extrapolate from experience with terrestrial mammals (including humans) and noise in air. The usual interpretation in the literature is that the threshold level for TTS becomes progressively lower as exposures become longer or more frequent. Thus ten exposures to a one-second signal of level 180 dB may cause the same TTS as a single exposure to a one-second signal at 190 dB. Recent environmental assessment documents have reduced thresholds by anywhere from 1 dB to 5 dB for each doubling of exposure time. This is a wide range, with the 'equal-energy' rule in the middle (3 dB per doubling). The effect of exposure time on behavior is usually treated in a similar way, but usually without the quantifiable effects available from TTS data.

For the ECSWTR DEIS and similar cases involving hull mounted sonars, the multiple exposure issue must include consideration of the ship's movement through the field of animals. Using expected surface ship speeds, sonar repetition rates, etc., the likelihood of an animal being in the ship's moving harassment zone long enough to suffer multiple exposures must be calculated. For the most powerful sonars (the ones that pose the risk for the ECSWTR case), the geometries led to an expectation of a 2-3 pings. The corresponding harassment threshold reduction for a behavioral effect is not known, but the equal-energy rule would yield 3 to 5 dB, and the 5 log N rule 2 to 3 dB. The value of 3 dB was selected, although it could have been 2 or 5 dB. This is not a critical element of the risk assessment. Hence, the ECSWTR use 177 dB as the threshold for multiple exposures.

For the foreseeable future, the Navy and the scientific community should acknowledge the criteria and thresholds of the Ridgway (1997) tests in assessing impact on dolphins from mid-range sonars. Sponsors of the study and ONR view the TTS question for small odontocetes and short exposure times as a solved problem. ONR's plans for future work on TTS focus on determining TTS thresholds for repeated exposures, longer exposure times, other species of mammal, lower frequencies, different waveforms, and impulsive sources (especially explosives).

<u>Precedent</u>

That Navy and the regulators have agreed previously on the application of the Ridgway (1997) results to risk assessments. The Ridgway results have become the *de facto* basis, and even broad extrapolations (e.g., to explosive sources, to different species, to multiple exposures) have been accepted by the regulators.

To indicate the prevalence of the use of the Ridgway (1997) results, the list below provides a sampling of recent Navy compliance documents that use those results. The list is by no means complete. References can be found at the end of this paper.

<u>Compliance Documents with Harassment Thresholds Based on Ridgway Tests</u>

a) LWAD 99-1 EA (1999), sponsored by ONR and approved by NMFS
[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

b) LWAD 99-2 EA (1999), sponsored by ONR and approved by NMFS

[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

c) LWAD 99-3 EA (1999), sponsored by ONR and approved by NMFS
[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

d) LVBDS EA (1998), sponsored by ONR and approved by NMFS
[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

e) SH-60R/ALFS EA (1999), sponsored by NAVAIR PMA-299
[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

f) ProPatria II EA (1997), sponsored by CNO (N87) and approved by NMFS
(Thresholds based on both TTS and behavioral results from Ridgway 1997)

g) ACOMMS EA (1999), sponsored by NAVSEA/ASTO and PEO(USW), and approved by NMFS
[Thresholds based on both TTS and behavioral results from Ridgway (1997), applied to all but the large whales.]

h) SEAWOLF Shock Trial FEIS (1998), sponsored by NAVSEA-PMS 350 and approved by NMFS
[Thresholds based on TTS results from Ridgway (1997), applied to all whales/dolphins.]

i) AUTEC ER (1997), sponsored by NUWC and approved by NMFS
[Thresholds based on TTS results from Ridgway (1997), applied to all whales/dolphins.]

j) AN/SQQ-89 OEA (1999), sponsored by NAVSEA PMS 411 and approved by NMFS
[Thresholds based on both TTS results from Ridgway (1997), applied to all whales/dolphins.]

What is notable in the list is the large number of Navy compliance documents that NMFS has approved (or co-sponsored) that rely on the Ridgway results for harassment.

Recapitulation

The 'science' is clear on the subject of the impact of 1-second sonar tones on dolphins: significant TTS is consistently observed for sound levels above about 190 dB (re 1 micropascal) and behavioral reactions are observed at levels above about 180 dB.

Most Navy environmental planning documents addressing underwater sound sources that may impact marine mammals have applied the Ridgway (1997) results to their risk assessments, and received approval of the approach from the regulators. In fact, the regulators have more than once endorsed TTS as a harassment criterion and the above mentioned levels as appropriate

thresholds. If this approach were to be challenged in court, this is one of the few cases for which controlled measurements exist and the science supports the approach. The technical community may have arguments over details and interpretation about the severity of the effects, but will generally endorse the Ridgway results. It is unknown whether Dr. Ridgway himself would endorse the use of his test results in the ECSWTR DEIS, particularly the treatment of multiple and prolonged exposures.

Use in the ECSWTR DEIS of a harassment threshold of 180 dB for a sonar signal of short duration (at most a few seconds) seems to be consistent with the Ridgway results - using a level lower than both the TTS (192 dB) and behavioral thresholds (186 dB), but allowing for a received signal duration beyond one second. A further reduction of the threshold to 177 dB for multiple exposures is likewise consistent with the Ridgway observations and the typical lengths of times that dolphins would remain within harassment range of a Navy ship in a tactical scenario with a high-power sonar.

Issues for the Ridgway et al. TTS Tests (1997)

(a) One is that the high ambient noise levels, with added masking noise, may preclude measurement of low levels of TTS, i.e., the 'onset' of TTS. This has been brought up in Kastak et al (1999), the SURTASS-LFA DEIS (1999), and elsewhere. This is the reason that the text notes that the Ridgway TTS thresholds (i.e., levels in the range from 192 dB to 201 dB) may be higher than those that would be measured for onset of TTS in a less noisy environment. The conclusion used here is that significant levels of TTS were measured repeatedly in Ridgway (1997), and that these levels may be higher than for onset TTS.

(b) The second issue is that of the interpretation of behavioral reactions for trained, captive dolphins. It is argued that the tests were not designed to address behavior, and that any conclusions are speculative. No one, however, disputes the fact that the animals consistently reacted to signal levels above about 180 dB.

Behavioral Changes -- Lower Bound: Estimated Levels at which Acoustic Signals in Water May Be Detectable

Based on hearing thresholds and measured critical ratios (recognition differentials for pure tones in white noise), we should expect that the threshold of awareness of a marine mammal to pure tone signals underwater in its band of hearing would be about 40 to 70 dB plus 20 to 40 dB or 60 to 110 dB (re 1 μPa). Measurements have indicated levels as high as 120 dB (NRC, 1994, and Richardson et al, 1995). Regulatory agencies (most recently, NOAA/NMFS) have, from time to time, proposed that intensity level as the legal limit, essentially making it a crime to expose marine mammals to intensities (for tones) greater than 120 dB. Nonetheless, the *de facto* level has been 150 dB (ATOC, 1993) to 160 dB for the last four years – for prolonged exposures.

Two important factors are important in determining levels of awareness for marine animals: the hearing sensitivity of the animal in the frequency band of the signal and the ambient sea noise in

that band. Measurements of hearing thresholds for several species of toothed whale typically lie in the range of 40 to 70 dB (re 1 μPa) for a short duration (1 second) pure tone in the band between 10 and 90 kHz. On the other hand, these whales are essentially deaf at frequencies below about 1 kHz. Baleen whales have significant hearing sensitivity only for frequencies below about 1000 Hz. Hearing thresholds have not been measured on these large whales, but can be expected to be toward the lower end of the interval from 60 to 90 dB, the normal range of ambient sea noise in the 10 to 200 Hz band.

APPENDIX G. BACKGROUND ON THRESHOLDS FOR IMPACT OF UNDERWATER NOISE ON SEA TURTLES

This appendix is organized according to the following outline:

G.1 IMPULSIVE NOISE

G.1.1 Thresholds for Injury

The thresholds of Section 6 are based on only a few references. These are summarized below.

G.1.1.1 O'Keeffe and Young (1984) - Sea Turtles and Explosives
The O'Keeffe and Young (1984) report recommends a safe range for sea turtles for planning purposes of:

$$\text{Safe Range (feet)} = 200\ W^{1/3},$$

for charge weight (W) in pounds. Thus, 200 feet would be the estimated safe range for a one-pound charge, 2000 feet for a 1000-pound charge, and 4300 feet for a 10,000-pound charge.

These results are based on observations following a 1200-pound explosion off Panama City in 1981. In that case, a 400 pound turtle within 500-700 feet was killed, while 200-300 pound turtles were slightly injured at 1200 feet and not at all at 2000 feet. The O'Keefe and Young report then extrapolates the safe range according to the above formula, "based on cube root scaling."

There are no other conditions associated with the formula. Estimated safe range does not depend on turtle size or weight or depth, nor on any parameters affecting propagation of the sound waves (e.g., water depth, bottom properties, sound speed field, charge depth, etc.).

Young's formula can be compared to similarity equations to deduce an acoustic threshold for ideal conditions. The result is a peak pressure threshold of about 50 psi (231 dB re 1 μPa).

Hence, the metric for injury used by Young can be interpreted as peak pressure, under propagation conditions consistent with the conditions (namely, ideal conditions such as those for the similarity formulas). Note that impulse, energy flux density, etc. have different power relationships with charge weight.

The O'Keeffe and Young range of 200 feet times cube-root of charge weight thus corresponds to a peak pressure for injury to sea turtles of about 50 psi (for ideal environment, etc). The corresponding peak pressures for the experimental data listed would then be estimated as: 169 psi (242 dB) for mortality, 77 psi (235 dB) for slight injury, and 43 psi (230 dB) for no apparent injury.

It is important to bear in mind that a safe range can be a very valid and useful threshold, but that it inherently depends on source and animal depths, as well as sound propagation conditions. Except under ideal conditions, the safe range is of little use unless it can be corrected for changes in the environment and scenario. It is for this reason that thresholds must generally be specified in terms of the sound field at the animal (e.g., 43 psi peak pressure), rather than in terms of range or of the field near the source. Propagation estimates for the environment at hand can then be used to estimate safe ranges. The planning ranges given in the NSWC documents or O'Keeffe and Young (1984), Young (1991, 1992), etc. are consistent with a model for which the ideal similarity formulas apply. These ranges may not be appropriate for non-ideal conditions.

G.1.1.2 Klima et al (1988) - Sea Turtles and Explosives

The results of Klima et al (1988) are among the very few measurements of the effects of explosives on sea turtles. The results are summarized in the Florida Straits LOA (1994), where a table shows possible injury to 200 pound turtles for peak pressures in the 4 to 6 psi range. Such pressures would presumably be even more injurious to small and juvenile turtles.

The table in the LOA suggests a range of thresholds corresponding to turtle weight. Peak pressure thresholds of 5 psi (211 dB re 1 μPa) for small and 50 psi (231 dB re 1 μPa) for the largest turtles seem consistent with the data. The data also suggest 50% lethal thresholds of 20 psi (223 dB re 1 μPa) for small turtles and 150 psi (241 dB) for large turtles. Note as before that the safe and 50% lethal thresholds differ by only 10-12 dB.

G.1.1.3 Young (1991) - Sea Turtles and Explosives

Since 1991, most Navy compliance documents have used Young (1991) as reference for sea turtle (and other animal) injuries from explosives. It is used in the *SEAWOLF* FEIS (1998) and the Florida Straits LOA (1994). A formula for safe range of the same form as that of O'Keeffe and Young (1984) is recommended in Young (1991):

$$\text{Safe Range (feet)} = 560\ W^{1/3}, \quad \text{for charge weight } W \text{ in pounds.}$$

As in Appendix E, the similitude formulas are consistent with an estimated peak pressure threshold of about 15 psi (221 dB re 1 μPa).

There is thus a nominal reduction in the equivalent peak pressure threshold from about 50 psi (231 dB) to about 15 psi (221 dB re 1 μPa). This reduction is consistent with the Klima et al (1988) data mentioned above [i.e., 15 psi (221 dB) is approximately the geometric (decibel) average of the Klima et al estimates for small turtles (5 psi or 211 dB) and large turtles (50 psi or 231 dB)].

G.1.1.4 Compliance Documents: Injury and Harassment of Sea Turtles by Explosives

Because of the importance of precedent, this subsection reviews what has been used in some recent Navy compliance documents for explosives.

Compliance Documents-SEAWOLF Shock Test FEIS (1998)

The SEAWOLF FEIS (1998) compared the Young (1991) formula for injury of Sea Turtles against the injury 'safety' range for mammals, based on a criterion of 50% eardrum rupture and a one mile 'buffer' zone. The Young formula for the 10,000 pound explosive yields about 12,000 feet, nearly identical with the injury safety zone for mammals of 2 nmi. Take estimates were based on the 2 nmi range (without any additional buffer zone beyond the Young (1991) range). No adjustment to the Young formula was made to account for the shallow, range-dependent environment (given the Young formula cube-root law, the corresponding similitude equations for shock waves follow a 23logR rule for propagation loss). No adjustments were made for turtle sizes.

For harassment of sea turtles, the SEAWOLF FEIS (1998) used the same criterion (TTS) and the same thresholds as for marine mammals. In particular, data on turtle hearing was used to justify the elimination of explosive energy below 100 Hz, and thus the use of the harassment zone determined for odontocetes.

In the FEIS, behavioral responses for turtles beyond the TTS range (about 8.5 nmi) were estimated as not likely to be significant because of the fact that time between shots is long (order weeks) and duration of the signal short (listed as <50 ms). The latter argument may be unreliable since it is not unusual for the duration of significant arrivals from a shot signal in shallow water to significantly exceed 50 ms at a few miles.

Compliance Documents - Florida Straits LOA (1994) and NAWC/Gulf of Mexico EA (1993)

"Safe ranges" for sea turtles are provided in a table based on the Young (1991) formula:

$$\text{Safe Range (feet)} = 560\ W^{1/3}, \quad \text{for charge weight W in pounds.}$$

There is no depth dependence indicated. Harassment of sea turtles is not addressed.

G.1.1.5 Summary of Thresholds for Explosive Effects on Sea Turtles

Table D.2.5 below summarizes the thresholds given above.

For recently approved Navy compliance documents, the thresholds of Young (1991) and Klima et al. (1988) are most often used for injury. The peak pressure thresholds are all based on the same data, and are consistent. Range thresholds are for ideal conditions.

Table G.1-1 References for Thresholds for Physical Injury Caused by Impulsive Sound for a Single Event - Sea Turtles

Effect	Turtle Size	Metric	Threshold	Reference
50% Lethal	Large	Peak Pressure	150 psi (241 dB [a])	Klima (88)

50% Lethal	Small	Peak Pressure	20 psi (223 dB [a])	Klima (88)
'safe'	Large	Peak Pressure	50 psi (231 dB [a])	Klima (88)
'safe'	Small	Peak Pressure	5 psi (211 dB [a])	Klima (88)
'safe'	N/A	Range	200 $W^{1/3}$ feet [c]	O'Keeffe and Young (84)
'safe'	N/A	Range	560 $W^{1/3}$ feet [c]	Young (91)
'safe'	N/A	Peak Pressure [b]	50 psi (231 dB [a])	O'Keeffe and Young (84) [b]
'safe'	N/A	Peak Pressure [b]	15 psi (221 dB [a])	Young (91) [b]
Injury (except TTS)	N/A	Range	560 $W^{1/3}$ feet [c] Young (1991)	SEAWOLF FEIS (1998), NAWC (1993)
TTS	N/A	Greatest EFD[d] Level in 1/3 Octave Band above 100 Hz	182 dB (re 1 μPa^2-s)	SEAWOLF FEIS (1998) (same threshold as for TTS in marine mammals)

[a] dB re 1 μPa
[b] Peak Pressure metric deduced from Range metric using similarity formula.
[c] W is charge weight in pounds
[d] EFD is energy flux density

G.1.2 Thresholds for Harassment

The principal criterion for harassment of sea turtles by impulsive sources is TTS, as applied in the SEAWOLF FEIS (1998) and approved by NMFS. The threshold for sea turtles is the same as that used for odontocetes: an energy level of 182 dB (re 1 μPa^2-s) applied to 1/3-octave bands above 10 Hz for baleen whales and 1/3 octave bands above 100 Hz for odontocetes. As mentioned earlier, the equivalent energy level for the full frequency band is about 200 dB for a typical explosive signature. That is, it would take a signal with total energy level of order 200 dB to exceed 182 dB in the greatest 1/3 octave band above 100 Hz. Also note that the Ketten TTS threshold for mammals used as a dual threshold in SEAWOLF is a peak pressure of 12 psi. (218 dB re 1 μPa). For large shots at range, the corresponding energy modeled in the SEAWOLF FEIS would be about 185 dB (re 1 μPa^2-s) for the whole band.

In the FEIS, behavioral responses for turtles beyond the TTS range were estimated as not likely to be significant because of the fact that time between shots is long and duration of the signal short (listed as <50 ms). The latter argument may be unreliable since it is not unusual for the duration of significant arrivals from a shot signal in shallow water to significantly exceed 50 ms at a few miles.

G.2 NON-IMPULSIVE NOISE

Non-impulsive noise is not known to cause non-auditory physical damage to marine animals. The shock waves and large peak pressures of explosives are not found in projector signals. There have been no controlled measurements to determine PTS or other physical injuries to marine life from

projector signals. Note, however, that adverse physical effects are suspected for human divers exposed to low-frequency tones (below about 1000 Hz). These effects include possible lung resonance vibrations and inner ear disturbances. Whether or not marine animals suffer similar effects is not known.

ATOC (1995) and LFA-SRP have addressed the possibility of non-auditory injury to marine life from low-frequency sound. Otherwise, there is no recognition of significant non-auditory impact from projectors used in the Navy.

TTS has been used as a criterion for harassment of sea turtles in the *SEAWOLF* FEIS (1998), which applies to explosive sources. The energy threshold in the FEIS is the same as that used for odontocetes in the FEIS. PTS is not addressed.

Consider then the application of the TTS thresholds discussed at the NMFS Criteria Workshop (1998). Ketten recommended thresholds for PTS of about 200 dB (re 1 µPa) for a 1 second tone, 190 for 4 seconds, 180 for 16 seconds, 170 for 64 seconds, 160 for 256 seconds, and ...130 dB for 6 hours or more. These thresholds (which incorporate the Gisiner-NIOSH slope and 10 dB threshold increment for PTS over TTS) are so low as to cause even modest projectors to present a serious risk of Level A harassment. Any use of these thresholds must be avoided on the rationale (1) the slope is based on human hearing over long durations, (2) Ketten's estimate of PTS stimulus at 10 dB above TTS stimulus is based on terrestrial mammal hearing and does not account for the amount of TTS suffered, and (3) neither of the two data points on the curve (Ridgway TTS and Schusterman TTS) have received critical reviews, not are they published.

In summary, thresholds for marine mammals and sea turtles for behavioral harassment are suggested as follows:

180 dB for a 1 minute exposure
177 dB for 2 minutes
174 dB for 4 minutes
171 dB for 8 minutes
168 dB for 15 minutes
165 dB for 30 minutes
162 dB for one hour
160 dB for more than two hours

Decibel quantities are total SPL referred to 1 µPa. "Exposure Time" is roughly defined as the time over which signals arrive at the animal with a density of one every several minutes.

APPENDIX H. BACKGROUND ON THRESHOLDS FOR IMPACT OF UNDERWATER NOISE ON SEABIRDS AND FISH

H.1 IMPULSIVE NOISE

The principal sources cited in compliance documents for effects of explosive energy on fish, birds and invertebrates are Yelverton et al. (1973, 1981) and Young et al. (1992b).

Mortality and injury tables for impulsive sound have been established by experiment, and are given in terms of two metrics: peak pressure and positive impulse (Yelverton et al, 1973 and 1981). These thresholds were derived from tests using explosives and terrestrial animals and fish in water.

Scientists at CD-NSWC/UERD published a number of reports on the effects of explosives on a number of categories of marine animals (including turtles and mammals as discussed above). Results are summarized in such documents as Young (1991), O'Keeffe and Young (1984), and Young (1992b).

Table H.1-1 below is typical of what has been used in risk assessments. Note that the preferred metrics are positive impulse and peak pressure. Notice also that the difference in sound strength between 'safe' and 50% lethal is typically a factor of three to five (in pressure or impulse). This amounts to a difference of only 10 to 15 dB. Note also that Yelverton (1981) recommends a "safe" exposure level for all but the smallest marine animals of 5 psi-ms (the same as for a small fish or diving bird). The thresholds listed have been used in Navy and Air Force compliance documents for impulsive sources.

Table H.1-1. Thresholds for Mortal and 'Safe' Exposures to Explosives for Fish, Birds, Shrimp, Crabs

MARINE ANIMAL	METRIC	50% MORTALITY	'SAFE' STRENGTH
Bird on Water Surface	Positive Impulse	130-150 psi-ms (900-1035 Pa-s)	30 psi-ms (207 Pa-s)
Diving Bird	Positive Impulse	45 psi-ms (310 Pa-s)	6 psi-ms (41 Pa-s)
Shrimp and Crabs	Peak Pressure	50-200 psi (231-243 dB re 1 μPa)	15 psi (221dB re 1 μPa)
Fish (100 g)	**Positive Impulse**	**20 psi-ms (138 Pa-s)**	**5 psi-ms (35 Pa-s)**
Fish (1000 g)	Positive Impulse	50 psi-ms (345 Pa-s)	10 psi-ms (69 Pa-s)

Table H.1-2 Historical References for Criteria and Thresholds for Physical Injury Caused By An Explosive Sound Source For A Single Event - Fish, Birds, Shrimp, Crabs

Effect	Marine animal	Metric(s)	Threshold(s)	Reference
50% Lethal	Shrimp, Crabs	Peak Pressure	50 to 200 psi (231 to 243 dB*)	Yelverton (1981)
'safe'	**Mammals, Fish, Birds, Turtles, Some Invertebrates**	**Peak Pressure and Positive Impulse**	**5 psi (211 dB*) and 5 psi-ms**	**Young (91), Goertner (82)**
50% Lethal	Fish (0.1 kg)	Positive Impulse	20 psi-ms	Yelverton (1981)
50% Lethal	Fish (1 kg)	Positive Impulse	50 psi-ms	Yelverton (1981)
50% Lethal	Diving Bird	Positive Impulse	45 psi-ms	Yelverton (1981)
'safe'	Diving Bird	Positive Impulse	6 psi-ms	Yelverton (1981)

Perhaps most important is the estimate of 'safe' (from physical injury) positive impulse for birds, small turtles, small fish, and all marine mammals of 5 psi-ms [derived by Young (1991) from Yelverton (1981)]. The corresponding 'safe' impulse for human divers is 2 psi-ms (Christian and Gaspin, 1974). Unfortunately, the interpretation and calculation or measurement of positive impulse is not necessarily straightforward for impulsive sounds that do not have the characteristic waveform of an explosive in a free field. Propagation effects (such as multipath) and different waveforms (e.g., N waves of sonic booms) are examples.

H.2 NON-IMPULSIVE NOISE

As for mammals and turtles, physical injury (other than auditory) by non-impulsive noise has not been addressed as a significant possibility in risk assessments for fish, sea birds, etc. The possibility of injury from low-frequency noise should be considered. In the case of marine mammals and the SURTASS-LFA DEIS (1999), the injury threshold for a long pulse (tens of seconds) is an SPL of 180 dB.

For frequencies above about 1000 Hz, the tests of Ridgway et al (1997) suggest that one-second tones with levels as high as 200 dB cause no physical injury in dolphins. It is, however, a large extrapolation to fish, seabirds, etc.

Hastings (1996) is usually cited for the rule of thumb that injury to the inner ear of a fish may occur at levels of 90 to 140 dB above hearing threshold.

APPENDIX I. HEARING BANDS OF MARINE ANIMALS

I.1 HEARING BANDS OF MARINE MAMMALS

For PTS, TTS, and behavioral reactions of marine mammals to noise, there is an underlying consideration of the hearing capabilities of a given animal and the importance of that capability. Thresholds for harassment are usually very sensitive to assumptions about hearing bands. For example, in the SEAWOLF Shock Trial FEIS (1998), the threshold for harassment of baleen whales is based on TTS, and is calculated in terms of the acoustic energy flux density in the band above 10 Hz. Just as energy below 10 Hz does not affect the thresholds for baleen whales, the energy below 100 Hz does not affect thresholds for odontocetes. For the explosives treated, the energy that is not included far exceeds the energy content for the band above 100 Hz. This amounts to a raising of the threshold. On the other hand, for the same test, the alternate threshold for TTS provided by Ketten is based on peak pressure and includes the entire band for all mammal species. Examples given below indicate the widely differing conditions assumed in recent risk assessments.

Consideration must be given to the small set of measurements of the absolute hearing thresholds of small odontocetes and pinnipeds, of the vocalizations of marine mammals, and of the observations of animal reactions to noise at sea. There are additional considerations, for behavioral reactions, of the ability of an animal to detect a sound in the presence of ambient noise or masking, and the significance of the frequency content of the sound to the animal.

Most compliance documents provide general statements about the likely hearing capabilities of marine mammals. Typical is one which estimates hearing bands of odontocetes to extend from below 1 kHz to frequencies of order 100 kHz, and of mysticetes to extend from below 10 Hz to above 25 kHz. Large odontocetes (especially sperm whales) are estimated to use their hearing capability in the low band, as are certain pinnipeds (elephant seals, california sea lion).

Because estimates of injury and harassment can be very sensitive to the hearing band estimate, the above general statements must often be refined. Recent examples of approved compliance documents and NMFS announcements are illustrative of the scope of choices.

I.1.2 Distant Thunder ER (1998)

Odontocete hearing in the presence of explosives is assumed to be representative at 2500 Hz. Spectrum of explosive signal implies odontocetes are not affected by sound energy below 2500 Hz, and are not vulnerable to explosive sound with total energy on the order of 200 dB (re 1 μPa^2-s). The same logic is applied to baleen whales at 500 Hz, thus eliminating the band below 500 Hz from risk. The effective hearing band of odontocetes for the DISTANT THUNDER ER is then the band above 2500 Hz. For mysticetes, it is the band above 500 Hz.

The resulting reductions in energy source level (or increases to the harassment thresholds) for several different types of small explosives range from 37 dB to 24 dB.

I.1.3 SEAWOLF FEIS (1998)

The SEAWOLF FEIS treatment of hearing capabilities for marine mammals and large explosives is linked to TTS as the criterion for harassment. Specifically, the energy threshold for harassment is applied to 1/3-octave bands above 10 Hz for baleen whales and 1/3 octave bands above 100 Hz for odontocetes. For the 1/3 octave-band threshold used (182 dB re 1 μPa^2-s), the predicted "safe" ranges for mysticetes is about 12 nmi and for odontocetes about 8.5 nmi. At their "safe" ranges, the mysticetes would receive energy band levels of about 190 dB in the small band below 10 Hz, about the same as the total energy for the band above 10 Hz. For the odontocetes at 8.5 nmi, total energy received in the band above 100 Hz is about 185 dB, while total energy in the small band below 100 Hz is about 195 dB. (Estimates based on spectra in the FEIS). Hence, of the total energy of the explosive sound at the safe ranges, about 50% is eliminated on the basis of baleen whales hearing below 10 Hz and about 90% of the energy is eliminated on the basis of odontocete hearing below 100 Hz.

The choice of a lower "limit" on odontocete hearing is especially crucial for explosives and low-frequency projector arrays (such as the SURTASS-LFA system). For examples, from the predictions of the spectra in Appendix E of the SEAWOLF FEIS, the "safe" range for TTS is no less than about 12 nmi when the lower end of the relevant hearing band for odontocetes is any frequency above 100 Hz. However, if the cutoff were 40 Hz, then the estimated safe range would be reduced to about 8.5 nmi (the same as the safe range for baleen whales). The resulting take estimate for odontocetes would then double.

I.1.4 LWAD (1998, 1999, 2000)

For several of the LWAD Environmental Assessments involving explosives, the energy threshold of SEAWOLF was applied, but with the small odontocete threshold applying to only the energy above 1000 Hz. This is in recognition of the significant decrease in hearing sensitivities measured for at least nine species of odontocetes. Since the criterion is TTS, and not behavioral change, this approach can be defended on the basis of likely increase in stimulus levels to cause TTS, as well as the argument that the band below 1000 Hz may not be important to the small odontocetes' overall hearing capabilities.

Other risk assessments have used a variation of this approach for explosives - including the STANDARD EIGER EA (1995).

I.1.5 NOAA/NMFS, 1998, Final Rule, SEAWOLF: Comment on Hearing Bands of Marine Mammals

"Based on current scientific information, the low frequency of the explosive would potentially affect only marine mammals with the ability to detect low frequency sounds, mainly mysticete and sperm whales." (63 FR 66069 to 63 FR 66077, 1 December 1998, re Comment 7)

I.1.6 NMFS Federal Register, 1995, IHA Seismic SoCal: Hearing Bands

Excerpts from 60 FR 53753-53760, 17 October 1995. NOAA/NMFS: Notice of IHA for "Small Takes of Marine Mammals Incidental to Specified Activities; Offshore Seismic Activities in Southern California"

"In the proposed authorization, NMFS stated that dolphin, porpoise, seal, and sea lion hearing is believed to be poor at frequencies less than 1,000 Hz, and thus it is unlikely that the airgun noise would significantly affect them. One commenter correctly pointed out that ``significantly affect a marine mammal is not the appropriate criterion, and that the appropriate criterion is that the activity have a negligible impact. This commenter recommended NMFS provide a more thorough rationale for the determination that species other than large whales will not be taken by harassment incidental to the seismic surveys and that the takings of large whales will be limited to harassment.

"Within the pinniped suborder, Schusterman et al. (1967) have determined that none of the species tested to date have exhibited good hearing capabilities at low frequencies, although the northern elephant seal, California sea lion, and harbor seal appear to have some communication ability within the upper low-frequency band (100-1,000 Hz). Underwater audiograms indicate that pinnipeds and odontocetes are particularly sensitive to sound with frequencies in the 2-12 kHz range (Richardson et al., 1991). Seals and sea lions have thresholds of roughly 60 to 80 dB (re 1 μPa) in the range of best hearing. Phocid seals have lower thresholds and a wider frequency range of hearing than otariid seals. Pinniped hearing in sub-1 kHz range varies from 85 dB at 1 kHz to 114 dB at 250 Hz for the California sea lion, 70-85 dB at 1 kHz for the harbor seal, and 95 dB at 1 kHz for the northern fur seal (Richardson et al., 1991). No information has been reported concerning the in-water hearing of northern elephant seals (Richardson et al., 1991), although Schusterman (as cited in Advanced Research Projects Office, 1995) believes they may have mid- to low-frequency hearing ability.

"No studies have focused on pinniped reaction to underwater noise from pulsed, seismic arrays in open water (Richardson et al., 1991), as opposed to in-air exposure to continuous noise. However, assuming an SPL needed to be 80-100 dB over its threshold in order to cause annoyance and 130 dB for injury (pain), as is the current thought based upon human studies (ARPA, 1995), it appears unlikely that pinnipeds would be harassed or injured by low frequency sounds from a seismic source unless they were within close proximity of the array (114 dB^2 + 80 dB = 190 dB (harassment); 114 dB^2 + 130 dB = 244 dB (injury)). At the upper end of the seismic array's frequency (1 kHz), sufficient energy to cause harassment would occur at a distance of only 1-3 m from the source while TTS injury takes would not occur (70 dB^2 (harbor seal) - 85 dB^2 (California sea lion) + 80 dB = 150-165 dB (harassment); 70 dB (harbor seal) - 85 dB (California sea lion) + 130 dB = 200-215 dB (injury)).

"For odontocetes, based upon the best scientific evidence available, NMFS concludes that the hearing of dolphins, porpoises and other small whales that inhabit the Channel Islands area is poor at frequencies less than 1,000 Hz, and thus it is unlikely that the airgun noise would affect them. While odontocetes can hear sounds over a very wide range of frequencies, from as low as 75-125 Hz in bottlenose dolphins and belugas (Johnson, 1967; Awbrey et al., 1988) to 105-150 kHz in several other species (Richardson et al., 1991), underwater audiograms indicate that

odontocetes hear best at frequencies above 10 kHz. However, none of the seismic source frequencies will be within the dominant frequencies used by odontocetes for vocalization (Richardson et al., 1991).

"In the range of best hearing (10 kHz-90 kHz), odontocetes have thresholds in the range of 40 to 60 dB re 1 μPa. In the absence of noise, bottlenose dolphins can detect a signal of about 41-42 dB at various frequencies between 10 kHz and 100 kHz (Johnson, 1967, 1968). For frequencies from 100 Hz to roughly 1000 Hz however, hearing thresholds range from 130 dB to 90 dB re 1 μPa, suggesting the potential for an increased tolerance for low frequency sound. Other odontocete species appear to have similar threshold frequencies (see Richardson et al., 1991). If one accepts one commenter's premise and Richardson et al.'s (1991) conclusion, that, based upon studies on humans, SPLs of 80-100 dB over threshold are necessary in order to cause annoyance and 130 dB for injury (pain) in odontocetes, most odontocetes would probably need to be almost adjacent to the seismic source, and intentionally remain there, in order to be affected by the seismic array (110 dB[3] + 80 dB (harassment) = 190 dB; 110 dB[3] + 130 dB (injury) = 240 dB). At the upper end of the seismic array's frequency (1 kHz), sufficient energy would not occur that would cause either harassment or TTS injury takes to occur (90 dB[3] + 80 dB = 170 dB (harassment); 90 dB[3] + 130 dB = 220 dB (injury))."

"For odontocetes, based upon the best scientific evidence available, NMFS concludes that the hearing of dolphins, porpoises and other small whales that inhabit the Channel Islands area is poor at frequencies less than 1,000 Hz, and thus it is unlikely that the airgun noise would affect them."

\2\ Extrapolated from Figure 7.2 in Richardson et al. (1991).
\3\ Extrapolated from Figure 7.1 in Richardson et al. (1991).
(FROM: 60 FR 53753-53760, 17 October 1995)

I.2 HEARING BANDS FOR SEA TURTLES AND FISH

Much can be written about the hearing capacities of turtles and fish. This report, however, will limit the discussion to highlights of a few references that have been used in recent risk assessments. Just as for marine mammals, it is often quite important to be able to reduce or eliminate estimated risk of harassment for particular animals on the basis of poor hearing in the band of the noise.

I.2.1 Sea Turtles and Fish

Sea turtle auditory systems have not been well studied, but Ridgway et al. (1969) and Bartol et al. (1999) concluded that the upper auditory limit for two species (green turtle and loggerhead turtle, respectively) is about 1 kHz with maximum sensitivity below 800 Hz.

In general, fish perceive underwater sounds at frequencies below 2 kHz (Popper & Carlson, 1998).